

EXTENT, MAGNITUDE AND DECAY RATES
OF
TOTAL RESIDUAL CHLORINE
IN
SEWAGE EFFLUENT RECEIVING STREAMS

MOE
EXT
ANPB



Ontario

Ministry
of the
Environment

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EXTENT, MAGNITUDE AND DECAY RATES
OF
TOTAL RESIDUAL CHLORINE
IN
SEWAGE EFFLUENT RECEIVING STREAMS

by

S. F. Wisz, J. D. Ellis and C. Inniss

Chlorination Committee Technical Report No. 2
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ABSTRACT

Numerous reports in the literature, especially a review by Brungs¹, clearly outline the toxic effects to aquatic biota of residual chlorine found in wastewater effluents. Few of these studies though, have been concerned with the degradation of residual chlorine in receiving waters, since it was assumed that total residual chlorine was not persistent in most environments. To develop information and data with respect to the natural decay of residual chlorine in receiving waters, detailed summer and winter field investigations were conducted at several Ontario sewage treatment plants. Specifically, this study was aimed at assessing the effect of current chlorination practices on the extent, magnitude and decay of residual chlorine in streams receiving chlorinated effluents.

Samples submitted from transects within the stream were analyzed "on-site" for total residual chlorine, free available chlorine, monochloramine and dichloramine. A modified amperometric titration technique based on the procedure described in Standard Methods¹¹ and the method followed by the National Water Quality Laboratory, Duluth¹², was used for sample analysis.

At all survey sites, effluent samples contained significantly higher residual chlorine concentrations than the required minimum of 0.5 mg/L. These chlorine levels in the effluent resulted in residual chlorine being measured within the "zone of passage" at several survey locations. Downstream persistence of residual chlorine was noted to depend to a large extent upon the dilution ratio (i.e. streamflow to STP flow). Relatively fast degradation of residual chlorine occurred in receiving waters where the dilution ratio was greater than 20:1. Tables II, III and XII, and figures II (a) to (d), III (a) to (c) and XII describe the levels of residual chlorine found in the receiving waters below the outfalls of the Brantford, Alliston and Bolton sewage treatment plants. No further assessment of the data was performed at these three locations because the dilution was too great and the chlorine residual disappeared too quickly to allow for mathematical manipulation.

The data from the Aurora Creek site are presented in an overall and partial context. Decay curves, half-lives and calculated average decay coefficients are presented. Monochloramine was found to be the major chlorine fraction present in the streams during the summer survey with little or no measureable dichloramine. Increased dichloramine levels were obtained during the winter survey. No significant difference in decay rate

was exhibited between day and night sampling runs. Winter decay rates were approximately 3 - 5 times slower than the rate exhibited during the summer survey.

INTRODUCTION

Many investigators have expressed concern regarding the environmental effects of the discharge of chlorinated wastewater on the aquatic ecosystem. The accumulated data on chlorine residual toxicity including the work of Brungs², Tsai³, Zillich⁴ and Ellis⁵ overwhelmingly substantiate the position that detectable levels of chlorine and chloramines invariably indicate damage to aquatic biota. These data and others have prompted the setting of total residual chlorine criteria to protect fish and aquatic life. The levels proposed by the U.S. National Academy of Sciences⁶, the European Inland Fisheries Advisory Commission⁷, the United States Environmental Protection Agency⁸ range from 0.002 mg/L to 0.004 mg/L for continuous exposure of the most sensitive organisms. Similar recommendations are stated by the Great Lakes Water Quality Board of the International Joint Commission⁹ (IJC). The figure of 0.002 mg/L best represents the criteria developed by the majority of regulatory agencies for maximum safety.

Despite reported differences in the toxicities of free chlorine, hypochlorite radical and chloramines, total residual chlorine is the parameter providing the most practical guideline for toxicity evaluations. The total residual chlorine level of 0.002 mg/L is also the most frequently quoted detection level for amperometric determination which is considered to be the most sensitive and reliable method for residual chlorine measurement.

The criterion of 0.002 mg/L is usually applied to the periphery of an appropriately defined mixing zone as is stated by the Great Lakes Water Quality Board of the IJC⁹. Likewise, the Guidelines and Criteria for Water Quality Management in Ontario¹⁰ states that "every precaution should be taken to ensure that at least two-thirds of the total cross-sectional area of a river or stream is characterized by a quality which is entirely favourable to the aquatic community at all times".

Ellis⁵ compared these criteria and recommendations with accepted chlorination practices at sewage treatment plants in Ontario and identified certain areas of potential environmental concern.

The current policy on wastewater chlorination in Ontario is stated as follows:

"Mechanical sewage treatment plants are required to have chlorination facilities including a contact chamber in order to provide some reduction in coliforms prior to

discharge. The chlorine residual in the contact chamber discharge should be maintained at 0.5 mg/L during periods of required chlorination. Year-round chlorination is required at all these plants except in cases where there is no existing or potential impairment of water quality or water use. If a case can be established to support exemption from chlorination then this is for winter months November 15 to May 15 only."

The recommended total residual chlorine concentration which is required to provide a reduction in coliform, namely 0.5 mg/L, is far in excess of the suggested safe levels for the protection of the aquatic environment. Ellis speculated that under certain stream conditions (e.g. streamflow, stream morphometry) that sewage effluent total residual chlorine levels of 0.5 mg/L could conceivably create environmentally hazardous conditions. Ellis went on to state that there were, to date, no definitive comprehensive field investigations to assess the extent and magnitude of total residual chlorine in Ontario's receiving streams.

OBJECTIVES OF STUDY

The objectives of this study were as follows:

1. To assess the extent and magnitude of total residual chlorine in sewage effluent receiving streams as it relates to the mixing zone concept adopted by the Ministry of the Environment.
2. To estimate the decay rate of residual chlorine in receiving waters under natural conditions and to assess the effect of temperature on the decay rate.
3. To evaluate the results of the study in terms of Ontario's current wastewater chlorination practices and policies.

STUDY SITES

Field studies were carried out during summer and winter. The summer studies was carried out on streams which receive the chlorinated effluents of the Brantford, Alliston and Aurora sewage treatment plants. The winter study was repeated at the Aurora site; in addition, a study was carried out at a new location, namely the Humber River at Bolton. These sites were selected on the basis of their marked difference in stream morphometry and dilution capacity.

Summer Studies

Since this was the initial attempt at such studies, only three locations were selected for investigation. It was decided that accessibility to the laboratory facility and to the river downstream from the STP outfall would be major determinants in the site selection. A secondary consideration in the selection was that the sites provide a variety of STP to stream flow ratios in order to cover a wide spectrum of field conditions. The three sites selected were: the Grand River downstream from Brantford, the Boyne River downstream from Alliston and the Aurora Creek downstream from the Aurora STP. Under low streamflow conditions (7 Q_{20} - 95% chance of occurrence) the dilution ratios (streamflow to STP flow) at these locations would be: Brantford 25:1, Alliston 10:1, and Aurora 0:1.

At the time of the surveys, the ratios were actually 43:1, 23:1 and 1.3:1 respectively. Maps of each survey site are presented in Figures 1.1, 1.2 and 1.3.

Winter Studies

Similar study considerations were used in setting up the winter surveys. The two sites selected were the Aurora Creek downstream from the Aurora STP and the Humber River downstream from the Bolton STP. The dilution ratio (streamflow to STP flow) at the time of the survey was 1:0.97 for Aurora and 24.6:1 for Bolton. A map of the Bolton survey site is presented in Figure 1.4.

STUDY METHODS

Field Approach

Prior to conducting the intensive study, a preliminary investigation was carried out at each location to collect data on stream morphology and to determine dispersion characteristics of the effluent, sampling station locations, and times of travel from the STP outfall to each sampling station. Dispersion and time of travel studies were carried out using Rhodamine WT dye as a tracer. A fluorometer was used to measure the dye concentrations. During the intensive studies, the times of travel and plume dispersion studies were repeated in order to locate the sampling stations within the effluent plume. Sampling was usually carried out at five to nine transects; cross sectional sampling was carried out at some of the transects. No attempt was made to follow the same portion of effluent downstream and sample at precise times of arrival at the various transects. The sampling locations are shown in Figures 1.1, 1.2, 1.3 and 1.4. Samples for residual chlorine were collected in 1 liter glass bottles which had been previously "aged" overnight in tap water and rinsed with deionized distilled water, to ensure that residual chlorine would not be adsorbed onto the walls of the sample container. Analyses for residual chlorine were performed on site, while additional samples for BOD₅, TKN, NH₃, NO₂, NO₃, carbon, conductivity and chloride were transported "on ice" to the MOE laboratory in Toronto for analysis. In-situ dissolved oxygen and temperature measurements were only performed for the summer studies. The following average stream temperatures were recorded during the summer survey: Brantford 21°C, Alliston 21°C, and Aurora 19°C; and for the winter survey: Aurora 5.5°C and Bolton 0.5 °C. Sampling times were recorded at the time of sample collection. Table I shows the number of samples obtained at each station for the summer and winter surveys.

Sampling was carried out for a 24-hour period during the summer surveys and for a 15-hour period during the winter surveys. Streamflows were either measured or in the case of Brantford obtained from the Grand River Conservation Authority. STP flow records were obtained for the survey period from the STP operators.

Laboratory Approach

Analytical equipment for measuring residual chlorine was set up at each sewage treatment plant prior to the initiation of sampling. Residual chlorine analysis were performed using a modified amperometric titration technique based on the method outlined in Standard Methods, 14th ed.¹¹ and the method used by the National Water Quality Laboratory, Duluth, Minnesota¹². This modified method has a detection limit of 2 ug/L Cl based on chlorine standards.

Prior to the analysis of samples, chlorine standards were prepared on site from a stock solution, standardized using the iodometric procedure and analyzed amperometrically to ensure proper running conditions.

Samples were generally analyzed within 30 minutes of sampling for total residual chlorine, free available chlorine, monochloramine and dichloramine. At the Aurora site, upwards of one hour elapsed between sampling and analysis for some of the transects furthest downstream.

DISCUSSION OF RESULTS

Only the total residual chlorine data will be discussed in the case of Brantford, Alliston and Bolton study sites. For the Aurora study site both the total residual and monochloramine results will be discussed. Free available chlorine was not detected at any of the study sites. Sewage treatment plants which follow prescribed chlorination practices seldom produce a measurable free available chlorine in their effluents. The decay rates exhibited in the stream at the various study sites are a function of many factors. Some of these factors have been outlined by Snoeyink et al¹³ as follows: chemical composition of the water and bottom muds, exposure of the stream to sunlight, depth and turbulence, temperature, type of chlorine residual, extent and manner of dilution of the effluent when discharged to the stream and other factors. Draley¹⁴ further noted that the rates of decay cannot be predicted because many of the specific reaction rates are unknown and

because the rates of reaction vary with the organic material from system to system and perhaps season to season.

The background chemical data obtained at each site is not presented in this report but will be evaluated later to determine if a correlation exists between total residual chlorine levels and waste characteristics.

a) Brantford

The total residual chlorine results obtained for the Brantford study at five transects are shown in Table II. The average total residual chlorine concentration at the STP effluent was 1399 ug/L over the length of the survey. At the time of the study a 43:1 dilution ratio (stream to STP flow) was recorded. This high dilution ratio and the continuous mixing within the stream accounts for the majority of the variances in the total residual chlorine results. Figures II (a), (b), (c), and (d) profile the average total residual chlorine concentrations through the transects S, A, T and B.

The average total residual chlorine concentrations at the 1/3 stream width for transects S and A were 27 ug/L and 30 ug/L respectively. The remaining two transects, namely T and B, yielded total residual chlorine values close to or below 3 ug/L. Stations at transect C (3090 ft. and approximately 18 min. travel time) revealed no residual chlorine. No attempt was made to calculate a decay rate due to the relatively fast degradation of residual chlorine.

b) Alliston

The total residual chlorine results obtained at six transects for the Alliston survey are listed in Table III. These results include the data from the preliminary run in order to show the variations in total residual chlorine levels obtained during the survey. The average total residual chlorine concentration in the STP effluent for the survey period was 1187 ug/L. The dilution ratio at the time of the study was calculated to be 23:1 (stream to STP flow). The effects of the dilution ratio plus the fluctuations in STP hydraulic discharge and the continuous stream mixing process appear to account for most of the variations in total residual chlorine levels observed at the same location at different sampling times.

For all six sampling runs at transect A, total residual chlorine was determined only within a few feet of the shoreline even though the dye studies indicated that the plume covered a much wider zone (see Figure III (a)). At transect B, the average total residual chlorine concentration at the 1/3 stream width was approximately 8 ug/L for the four runs in which it was measured (see Figure III (b)). At transect C, the total residual chlorine levels were approximately 12 ug/L (see Figure III (c)). No residual chlorine was measured at either transect D or E.

During the study period, the plant operator lowered the rate of chlorine application for a short period but was requested to return it to normal operating conditions. Again no attempt was made to calculate a decay rate for the residual chlorine because of the rapid disappearance encountered.

c) Aurora

The results obtained for total residual chlorine, monochloramine and dichloramine are presented in Tables IV, V and VI for the summer survey and in Tables VII, VIII and IX for the winter survey. The Aurora site proved to be the most practical from the standpoint of monitoring the natural decay because of the stream morphometry and low dilution ratio. For the summer survey, samples were taken at the midpoint in the stream from transect B onwards. For the initial run of the winter survey, cross-sectional samples were taken at transects A to D to determine the location where the effluent was completely mixed with the stream. The results of this initial run revealed that the effluent and stream were almost completely mixed by transect C and measurement of the residual chlorine decay was initiated from this point onwards. Due to the low streamflow conditions which prevail in the Aurora Creek, the impact of the effluent upon the aquatic biota is massive. Since the sewage effluent flow constitutes such a large percentage of the total streamflow, it is quite obvious that the 2/3 zone of passage criteria is not being met.

Several assumptions have been made in presenting the residual chlorine decay rates, namely,

- i) no additional dilution inputs downstream
- ii) complete mixing occurred at transect C for the summer survey
- iii) time of travel did not change during the sampling runs.

Summer Decay Rates

During the summer survey the major component of residual chlorine present in the samples was the monochloramine fraction with little or no measureable dichloramine. The concentrations obtained from all sampling runs, for transects B through H were averaged for each transect and plotted against time as follows: \sqrt{c} vs t , $\log c$ vs t and $\frac{1}{c}$ vs t , in order to determine if the data was linear. Although all of the plots showed distinct curvature, i.e. nullifying overall 1/2, 1st or 2nd order kinetics, the $\log c$ vs t plot tended to fit the data best. A similar analysis of the average monochloramine concentrations for each transect produced identical results. Based on the information from these plots, one can examine the decay rate either from all of the points in the $\log c$ vs t plot or only the linear portion of it.

Assuming complete mixing at transect C, decay curves for total residual chlorine and monochloramine were obtained by drawing the curve of best fit and are shown in Figure IV (a) to IV (g) for each sampling run, transects C through H inclusive. Since the data did not fit any specific reaction order, half-life readings were taken directly off these curves and are presented in Table X (a). The variation in the half-life indicates that the decay rate depends upon initial concentration of residual chlorine and in this case does not tend towards 1st order kinetics. The likelihood that the same portion of the flow was sampled at each transect is remote and this fact may obscure a 1st order reaction. Furthermore although every attempt was made to measure each sample within a certain time period (30 minutes) from sampling, this was not achieved in every instance.

Looking specifically at the linear portion of the $\log c$ vs t plot, i.e. transect B through F, the average calculated decay rate coefficient and average half-life for both total residual chlorine and monochloramine are as follows:

	<u>TRC</u>	<u>Monochloramine</u>
average decay coefficient (k_d)	.0052/min	.0059/min
average half-life	58 min	51 min

The equation of the line would thus be: $c = c_1 \times 10^{-k_d(t-t_1)}$. One can propose that within a certain reach of the river, 1st order kinetics can be a very good approximation of the decay rate. Further downstream, other factors and reactions become more predominant thus variations in 1st order kinetics occur.

Winter Decay Rates

The Aurora STP which normally does not chlorinate during the winter months, agreed to chlorinate the effluent for a brief period (one week) to enable us to carry out our winter study. A preliminary sampling run was carried out on the morning of the study to provide some indication of residual chlorine levels and decay rate so that sampling transects could be adjusted if required.

A similar format of data analysis was followed for the winter total residual chlorine and monochloramine results. Decay curves for each sampling run are presented in Figures V (a) to V (c) inclusive. The times required for the total residual chlorine and monochloramine to decrease to one-half their concentration, taken from the point of complete mixing, were read directly off the decay curves and are appended in Table X (b).

As in the summer survey, an average decay coefficient and an average half-life was calculated for total residual chlorine and monochloramine based on the linear portion of the log c vs t plot (i.s. transects C to H), and are as follows:

	<u>TRC</u>	<u>Monochloramine</u>
average decay coefficient(k_d)	.0016/min	.0015/min
average half-life	188 min	200 min

In comparing the summer and winter decay curves for total residual chlorine and monochloramine, it is evident that temperature effects are quite prominent resulting in a decay rate difference of approximately 3 - 5 times.

Free ammonia results obtained during the winter survey were approximately double the summer values (i.e. ≈ 14 mg/L vs 7 mg/L). The dichloramine fraction measured during the winter survey was significantly higher than that measured in the summer. It has been noted that the distribution of reaction products is governed by the rates of formation of monochloramine and dichloramine which are dependent upon pH, temperature, time and initial Cl:NH₃ ratio. In general, high Cl:NH₃ ratios, low temperature and low pH favours dichloramine formation. This may be significant since some authors^{15, 16, 17} are of the opinion that the dichloramine fraction may be more toxic to fish than the monochloramine fraction.

The results of both surveys indicated that the concentration, residual chlorine fractions and decay rates were dependent upon the characteristics of the waste being chlorinated, and the various instream processes.

Water Quality laboratory studies (unpublished data) have shown that decay rates can vary greatly from hours to days depending upon the type of water chlorinated, i.e. sewage, river, tapwater and the temperature of the sample. Some typical results of the decay pattern are presented in Table XI. Although the lab studies were carried out under "static conditions" i.e. in a bottle, the results are nonetheless indicative of the significant variations which can exist in decay rates.

d) Bolton

During this study the Humber River was completely ice covered except for open areas near the outfall pipe. The residual chlorine levels in the effluent tended to fluctuate drastically due to several mechanical problems encountered with the chlorination system. The total residual chlorine results obtained for this survey are appended in Table XII. The average total residual chlorine concentration for the STP effluent was 5450 ug/L varying from a low of 2160 ug/L to a high of 7760 ug/L over the study period. Despite the low stream temperatures, the high dilution ratio (stream to STP flow) and other instream processes resulted in the dissipation of the residual chlorine within 19 min. travel time for two of the sampling runs and significantly reduced the total residual chlorine concentration (approximately 84%) on the third run. No attempt was made to determine a decay rate or assess the total residual chlorine levels within the 2/3 zone of passage.

ANALYTICAL TEST PROCEDURES

Orthotolidine vs Amperometric

Although a comparison of residual chlorine analytical methods was not included per se in the study objectives, a brief discussion is appropriate in view of some comparative data obtained during the study. Currently, most sewage treatment plants in Ontario use the orthotolidine disc comparator method for measuring residual chlorine in final effluents. The orthotolidine method has come under criticism during the past few years because of its poor accuracy and precision compared with other available methods resulting in the test procedure being deleted from the current edition of Standard Methods.

The minimal amount of in-plant total residual chlorine data available for the study periods was compared to the total residual chlorine results obtained by the amperometric procedure. In all cases, the orthotolidine method consistently measured 2 to 5 times lower than the amperometric method. For example, an OT reading of 0.5 mg/L total residual chlorine on the disc comparator could be anywhere from 0.5 to 2.0 mg/L lower than the amperometric value. The immediate result of replacing the current in-plant procedure with a more reliable method would be a significant reduction in total residual chlorine levels (closer to the actual value) and secondly a cost saving in chlorine usage. A comparison of various residual chlorine methods suitable for in-plant usage has been undertaken by the Water Quality Section with a report on the findings forthcoming.

CONCLUSIONS

1. The guidelines with respect to residual chlorine concentrations within sewage treatment plant effluents "zones of passage" were exceeded at several sites.
2. The sewage treatment plants in this study maintained on the average residual chlorine concentrations in the effluent upwards of 5 times the recommended minimum of 0.5 mg/L. Without tighter controls or a defined upper limit based on sound rationale, overchlorination is a possibility, since the economics of chlorination may not be a restraining influence.
3. The decay rate in receiving waters was highly dependent upon stream morphometry, dilution ratio, chemical and physical processes.
4. The decay rate of total residual chlorine in receiving waters during the winter study was, on the average, 4 times slower than the rate exhibited in the same stream for the summer study.
5. Total residual chlorine levels measured by the orthotolidine procedure consistently resulted in gross underestimations (2 to 5 times) compared with results obtained by the modified amperometric technique.
6. No significant variations in total residual chlorine decay were noted between day and night runs at the Aurora site.

RECOMMENDATIONS

1. In view of the slower total residual chlorine decay rate exhibited during the winter period, the present policy of winter chlorination should be reviewed for locations where downstream winter usage has no direct health implications.
2. Serious consideration should be given to replacing the present orthotolidine method with a more reliable procedure in order to achieve tighter chlorine control.
3. In view of the fact that most studies on fish toxicity have been undertaken in a "lab-type environment" with specific total residual chlorine species, the levels obtained may not be relevant to in-stream (STP) chlorinated species. It is recommended that in-stream studies should be initiated to properly assess the actual effects of total residual chlorine in zones of passage and mixing zones.
4. Since the present MOE policy on chlorination specifies a minimum limit of 0.5 mg/L total residual chlorine in the final effluent, it is recommended that an upper limit be established to minimize excess total residual chlorine being present in receiving waters.

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APPENDIX A

FIGURES

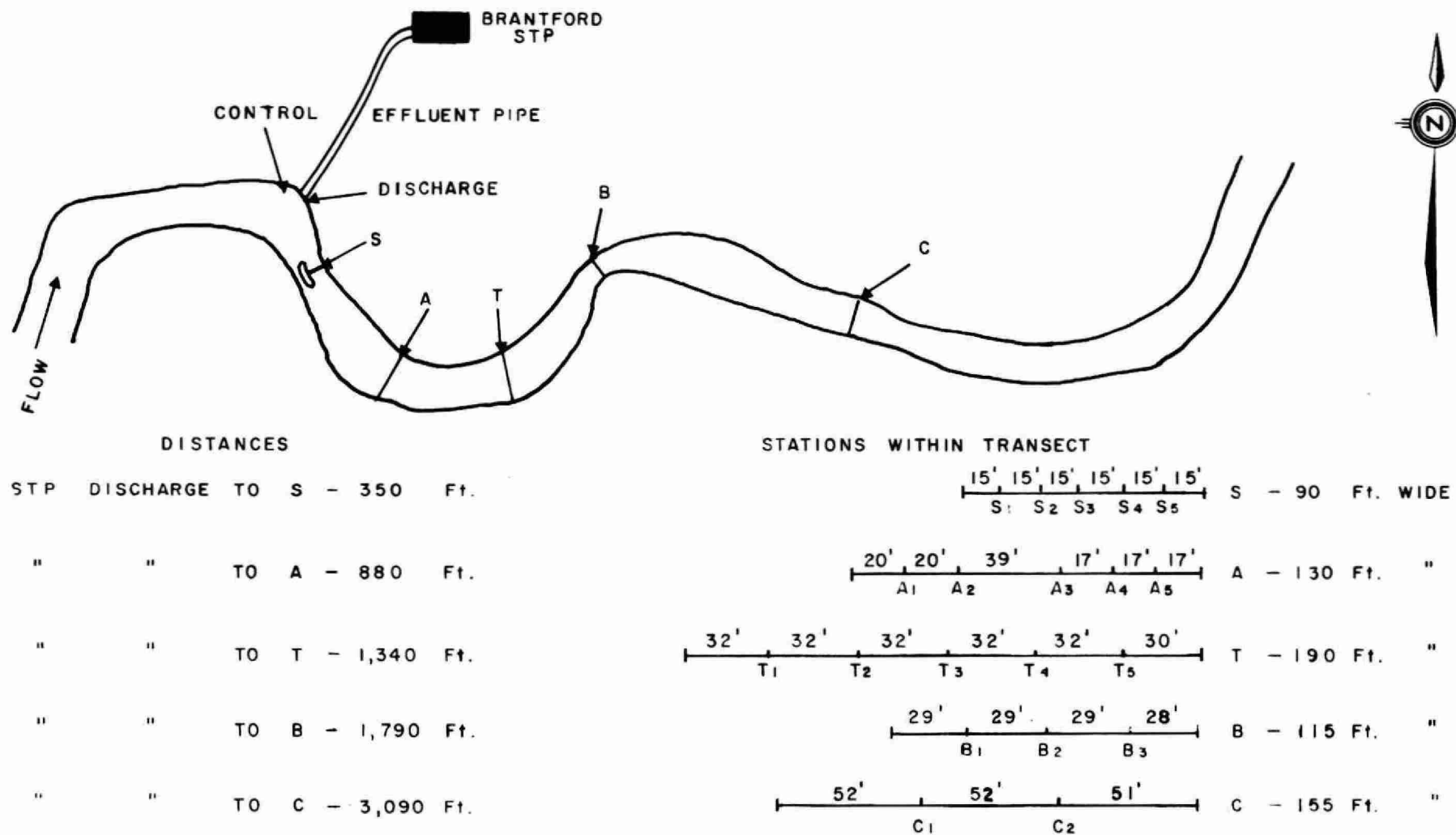


FIGURE 1-1 : SAMPLING STATION LOCATIONS - GRAND RIVER D/S BRANTFORD STP.

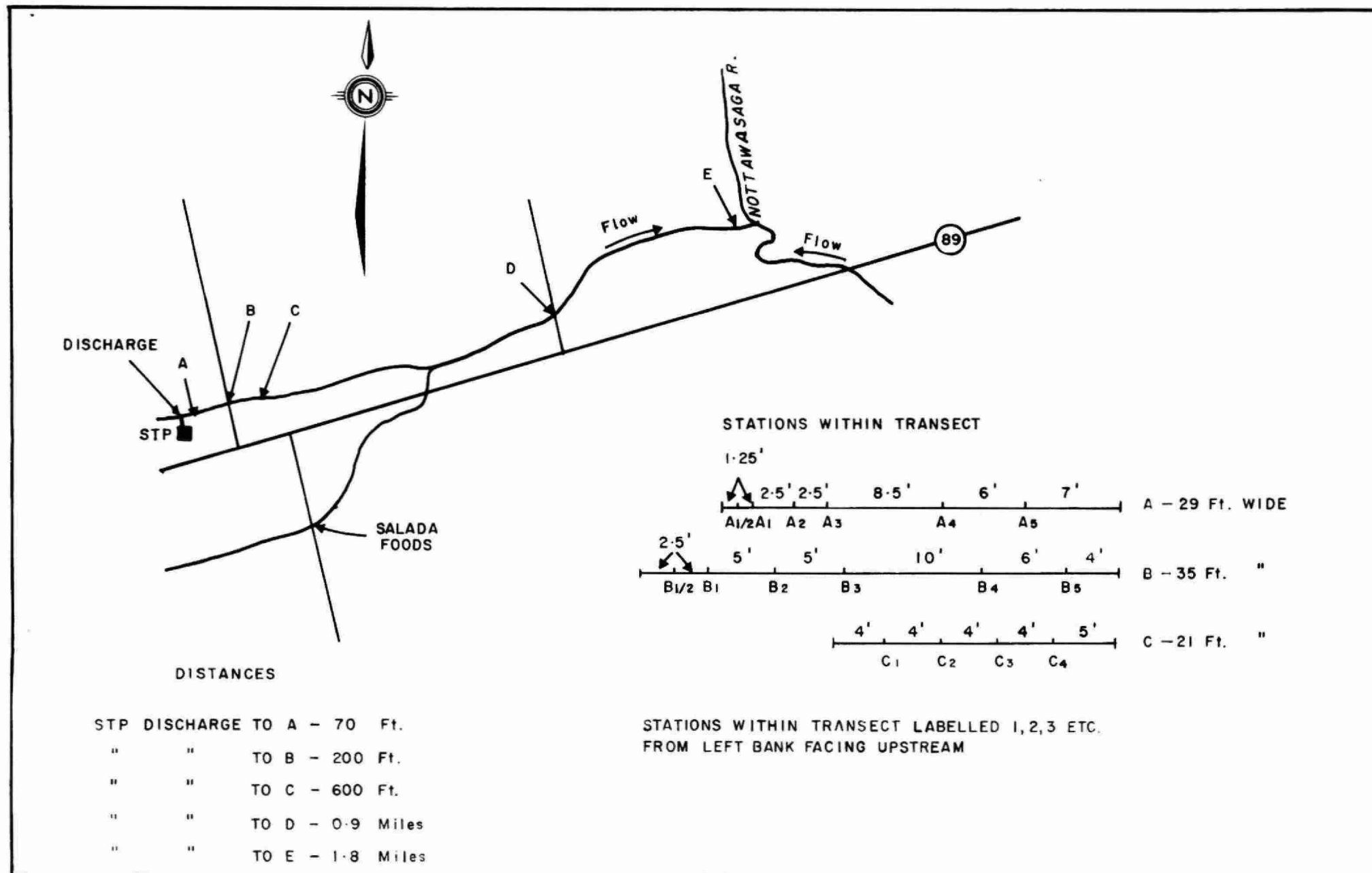
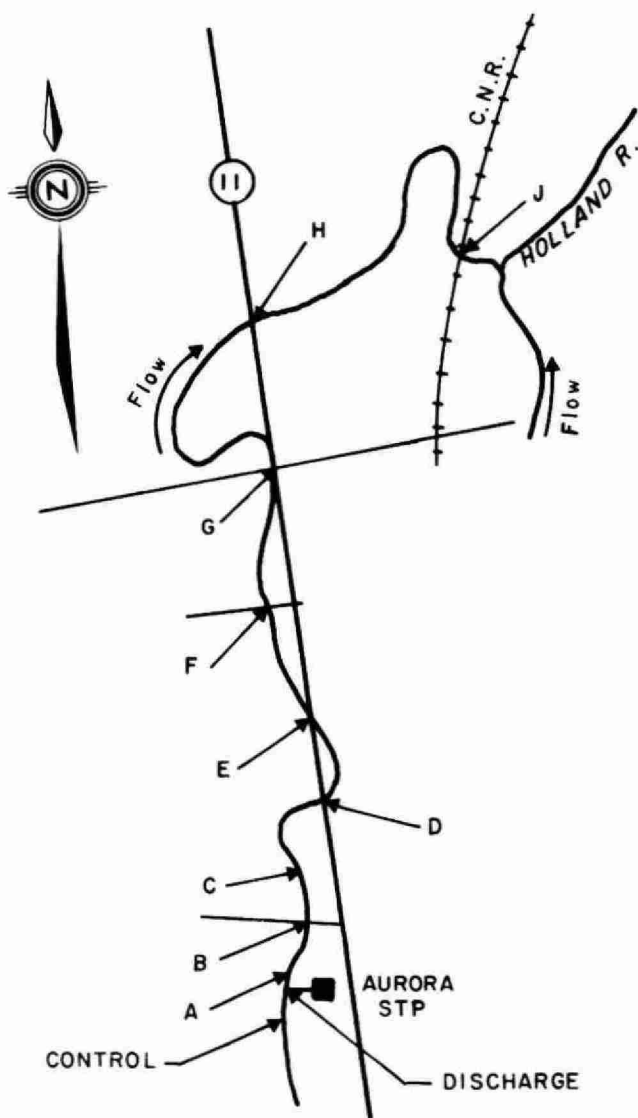


FIGURE 1-2: SAMPLING STATION LOCATIONS - BOYNE RIVER D/S ALLISTON STP.



DISTANCES

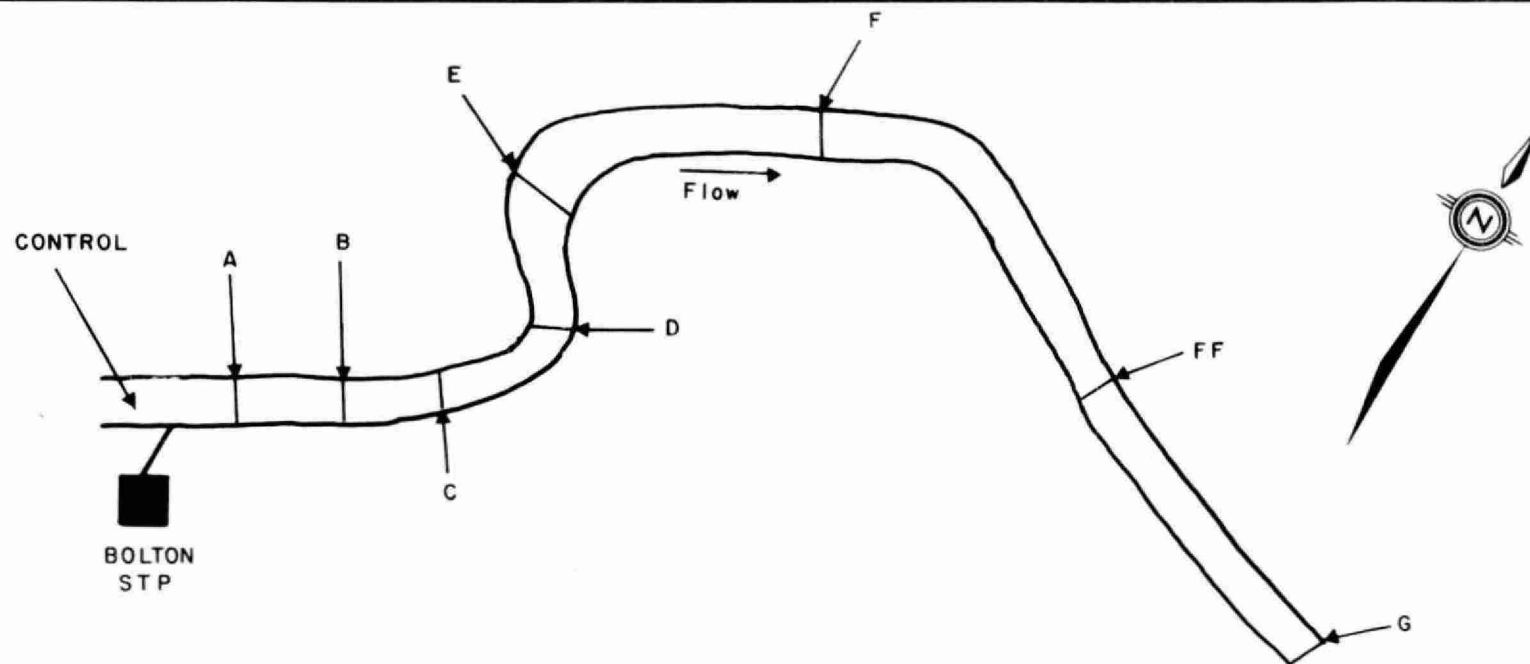
STP DISCHARGE TO	A - 50	Ft.
"	"	TO B - 300
"	"	TO C - 0.25
"	"	TO D - 0.40
"	"	TO E - 0.70
"	"	TO F - 1.00
"	"	TO G - 1.30
"	"	TO H - 1.80
"	"	TO J - 3.00

STATIONS WITHIN TRANSECT



STATIONS LABELLED 1,2 FROM LEFT BANK FACING UPSTREAM

FIGURE 1-3 : SAMPLING STATION LOCATIONS - AURORA CREEK D/S AURORA ST P.



DISTANCES

STP DISCHARGE TO A	- 25 Ft.
"	" TO B - 75 Ft.
"	" TO C - 125 Ft.
"	" TO D - 175 Ft.
"	" TO E - 275 Ft.
"	" TO F - 425 Ft.
"	" TO FF - 650 Ft.
"	" TO G - 900 Ft.

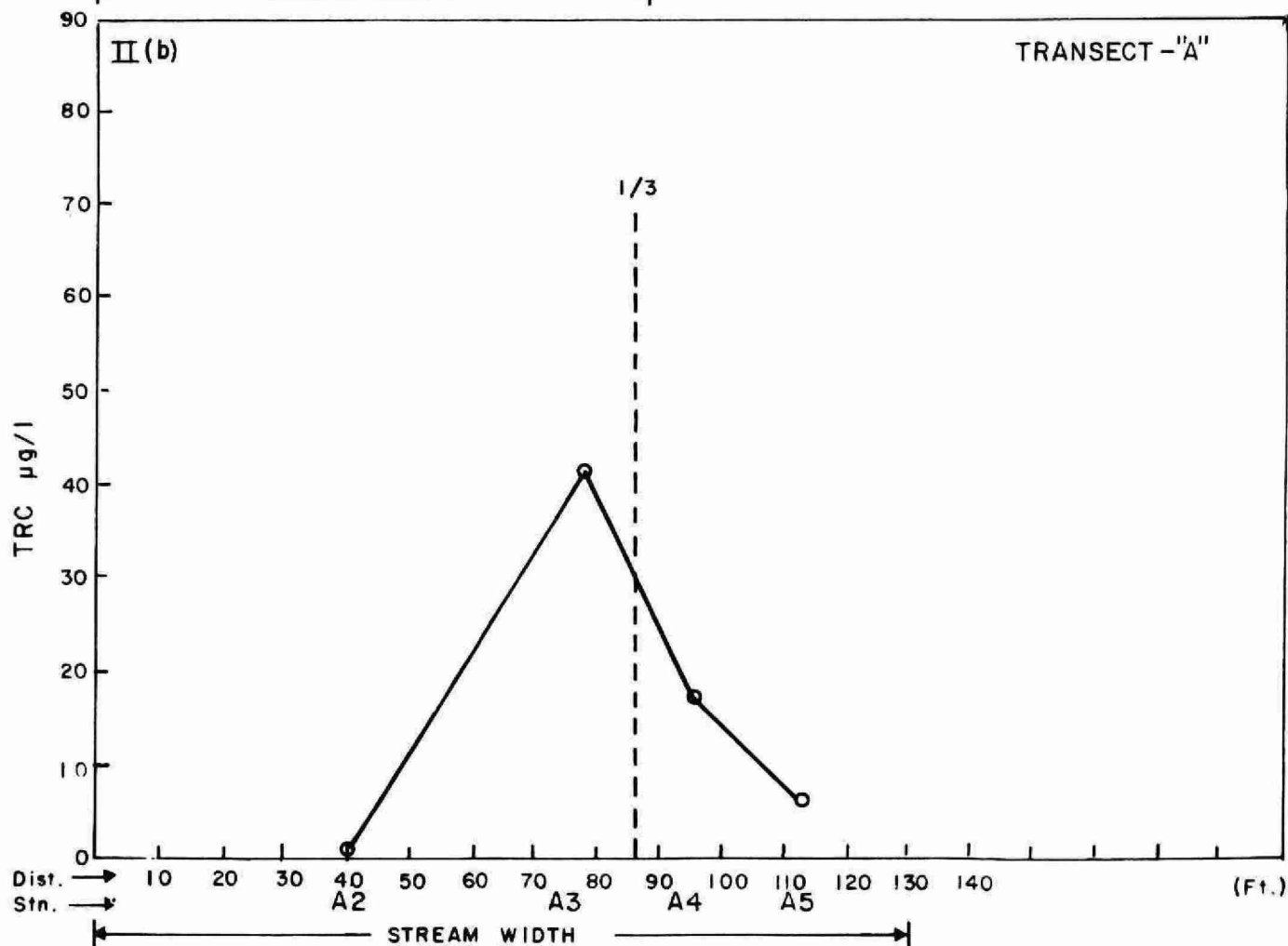
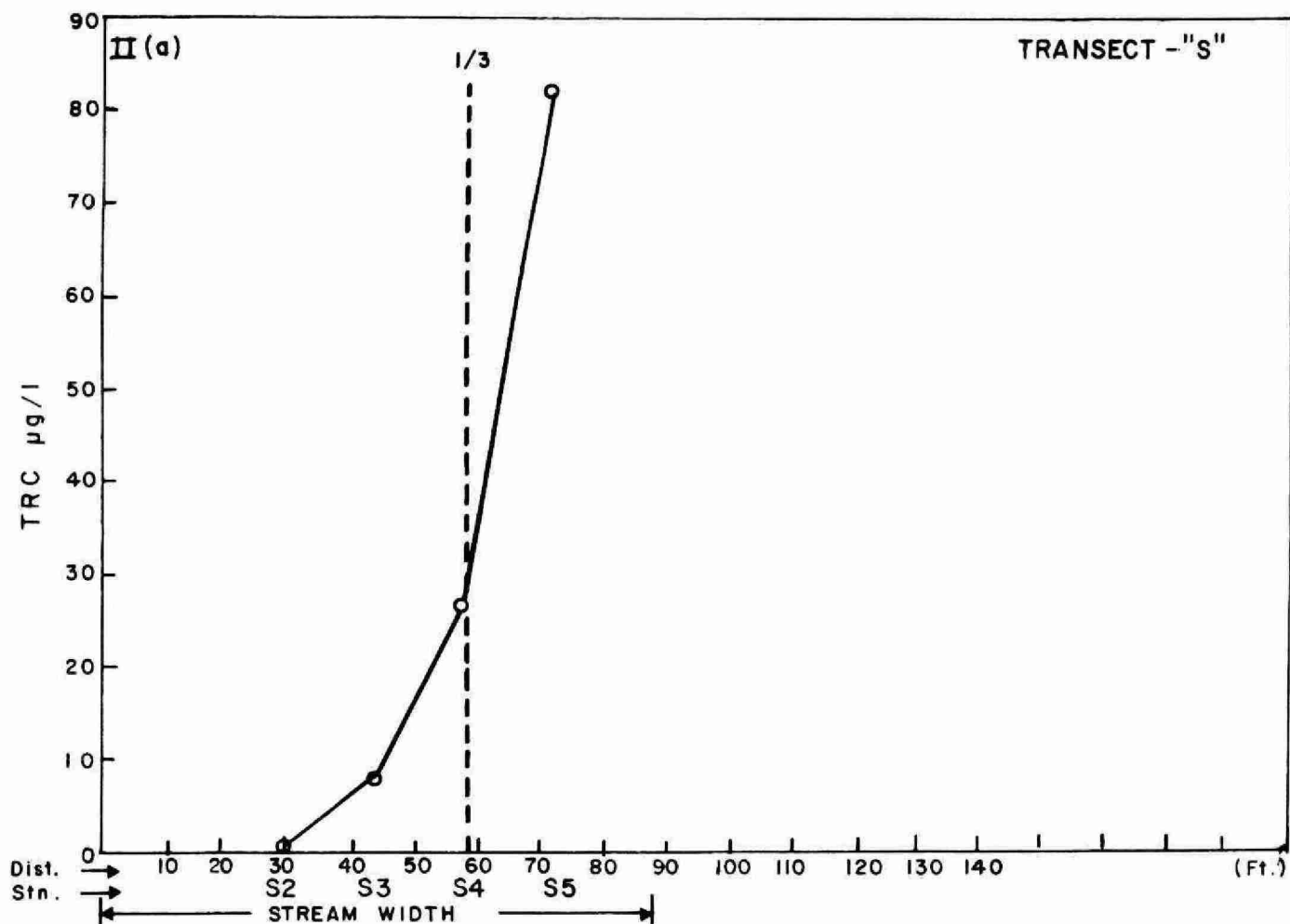
STATIONS WITHIN TRANSECT

4' 4' 3' 5' 27'	A - 43 Ft. WIDE
4' 4' 4' 9' 22'	B - 43 Ft. "
3' 7' 4' 12'	C - 33 Ft. "
6' 6' 8' 6' 7'	D - 33 Ft. "
7' 8' 8' 5'	E - 28 Ft. "
8' 8' 8' 9'	F - 33 Ft. "
F ₁ F ₂ F ₃	

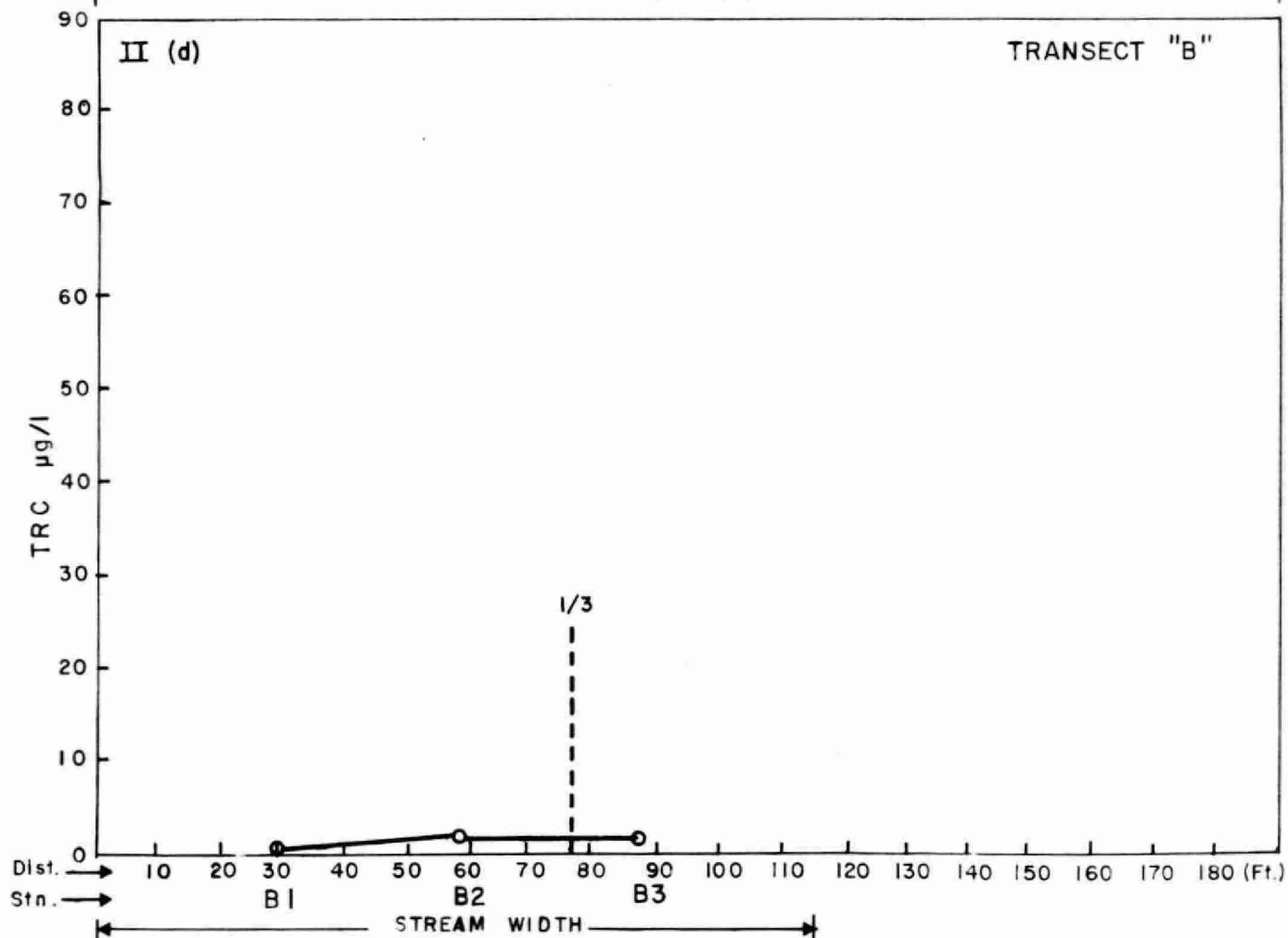
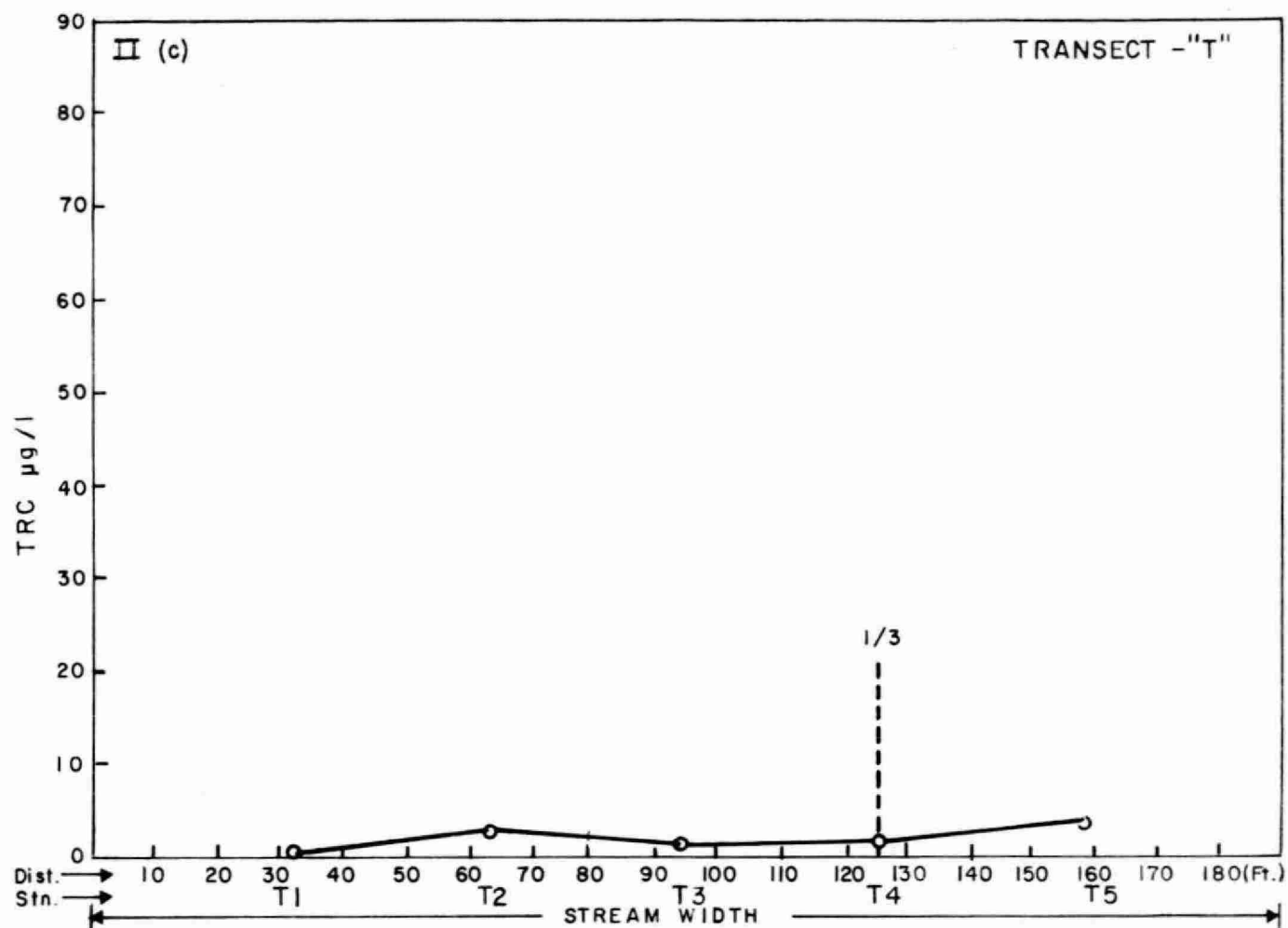
ONE STATION - MID-STREAM FF
ONE STATION - MID-STREAM G

STATIONS WITHIN TRANSECT LABELLED 1, 2, 3 ETC.
FROM LEFT BANK FACING UPSTREAM

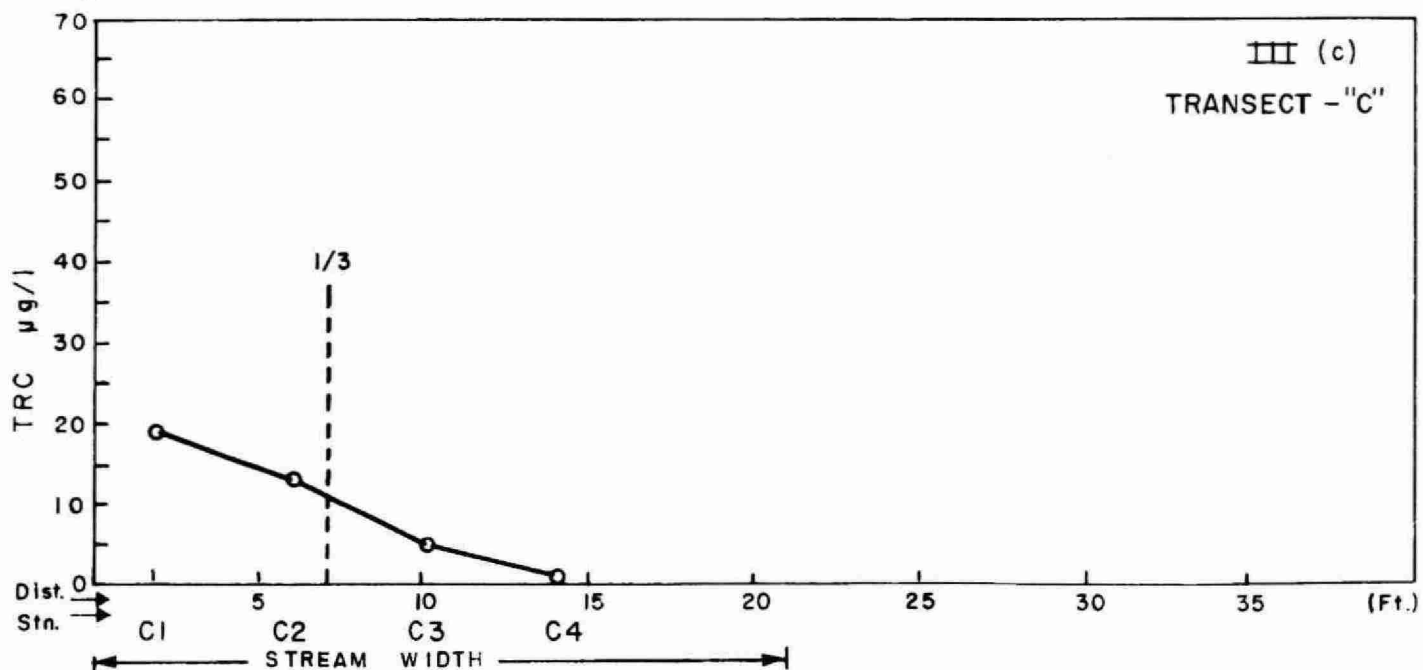
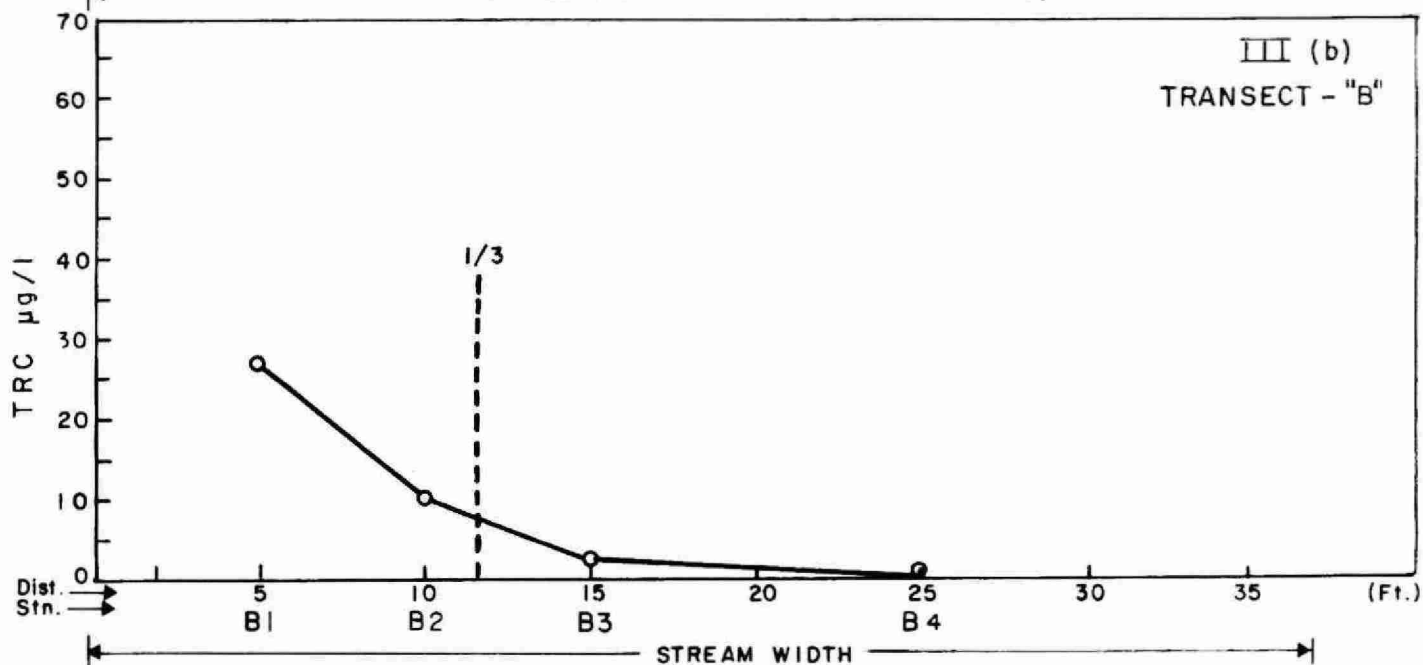
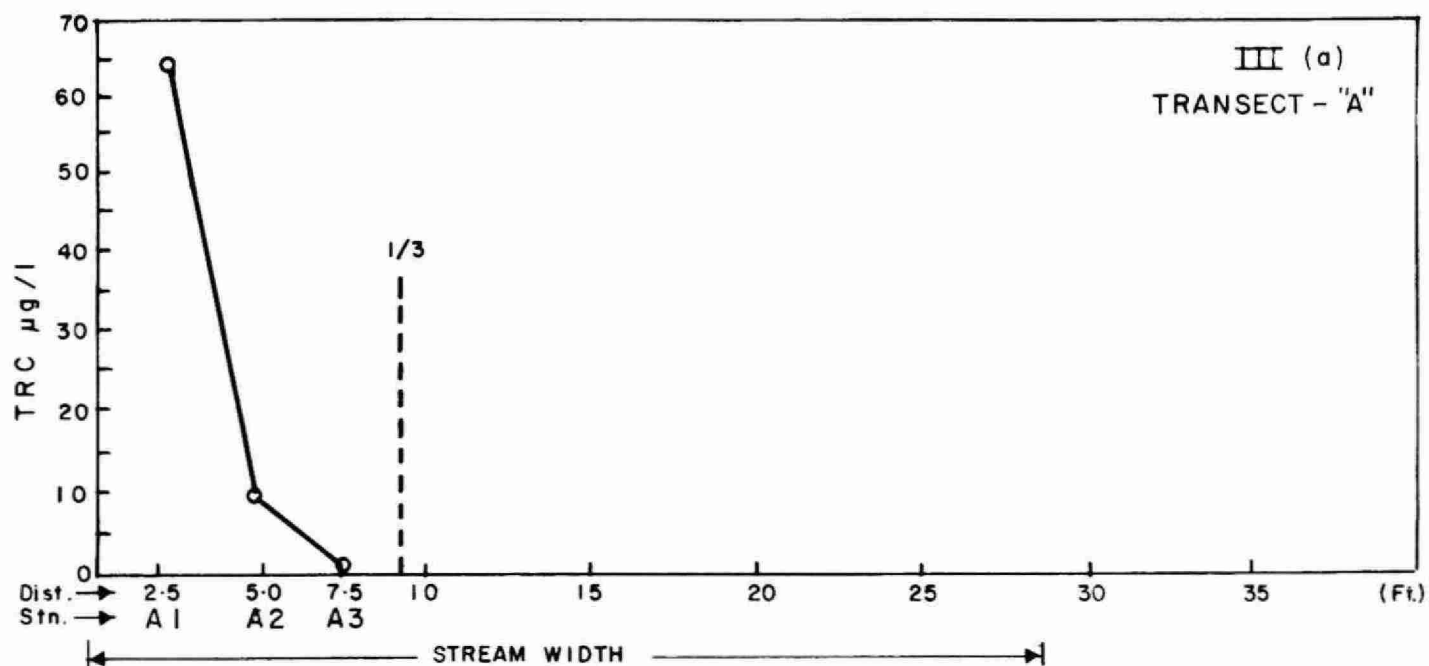
FIGURE 1-4 : SAMPLING STATION LOCATIONS - HUMBER RIVER D/S BOLTON STP.



FIGURES II (a) & (b) : MEAN TRC VALUES vs DISTANCE BRANTFORD - GRAND R.



FIGURES II (c) & (d) : MEAN TRC VALUES vs DISTANCE BRANTFORD — GRAND R.



FIGURES III (a) (b) & (c) : MEAN TRC VALUES vs DISTANCE ALLISTON - BOYNE R.

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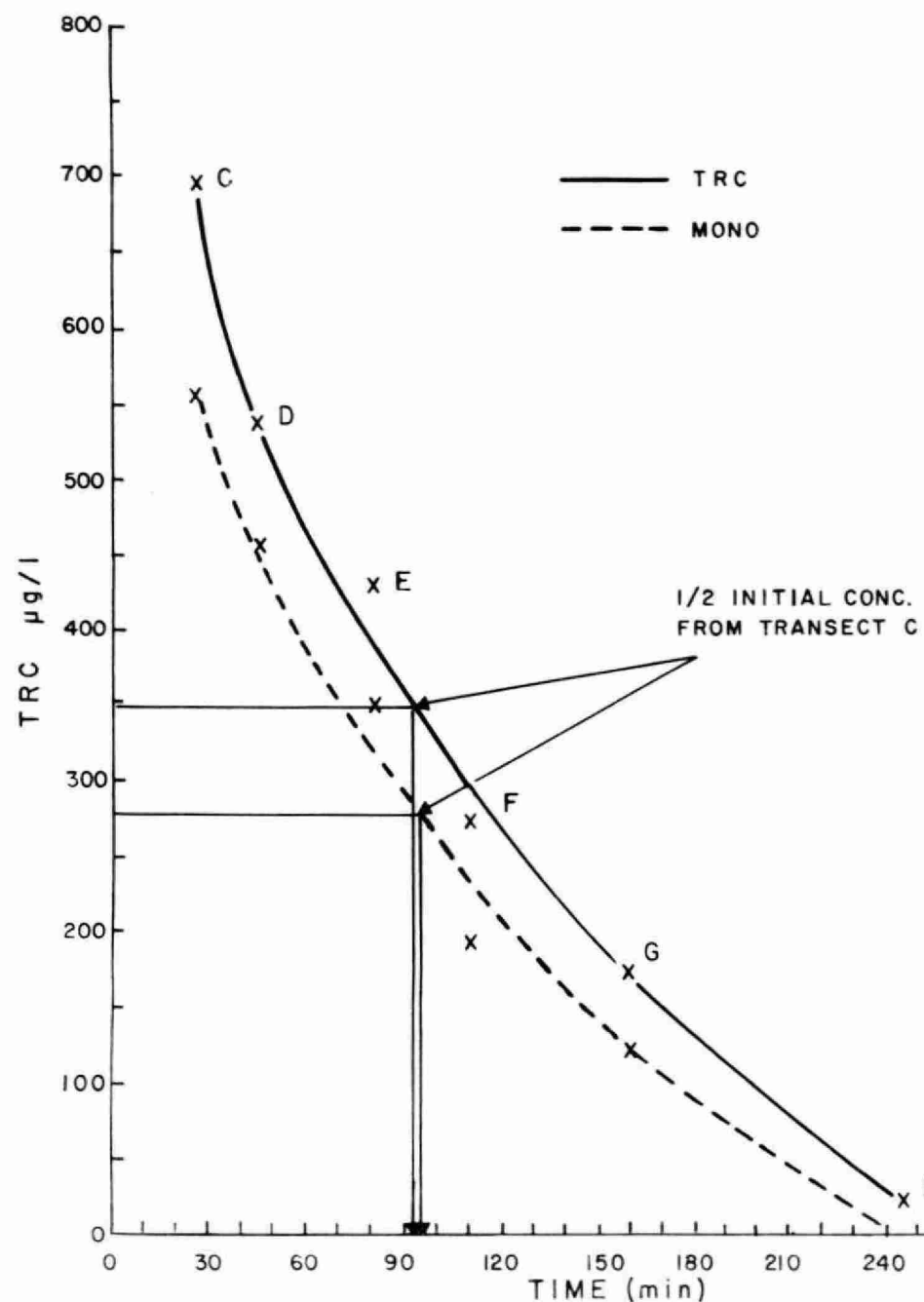


FIGURE IV (a): RUN N° 1 - AURORA CREEK AUGUST 18, 1976

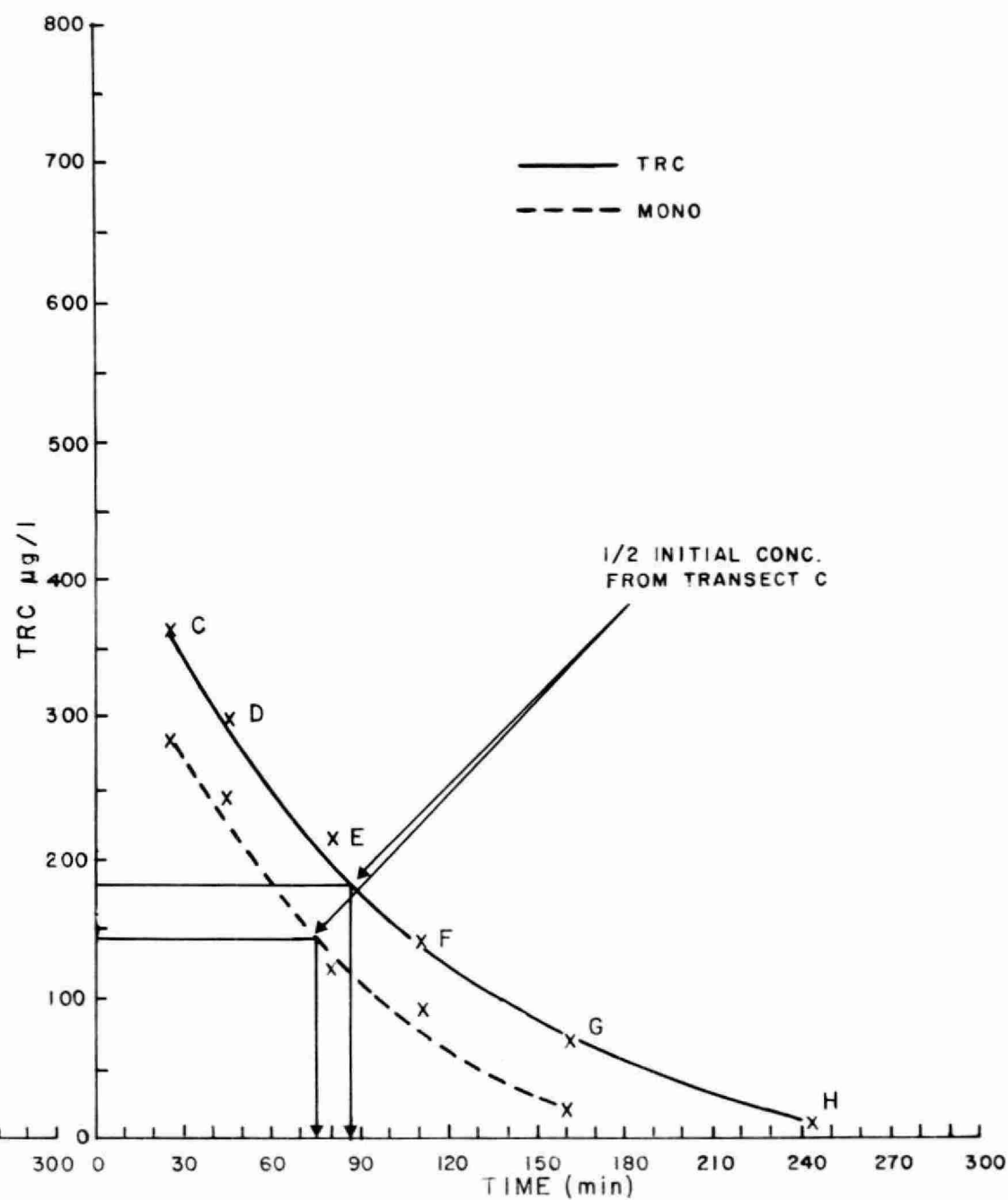


FIGURE IV (b): RUN N° 2 - AURORA CREEK AUGUST 18, 1976

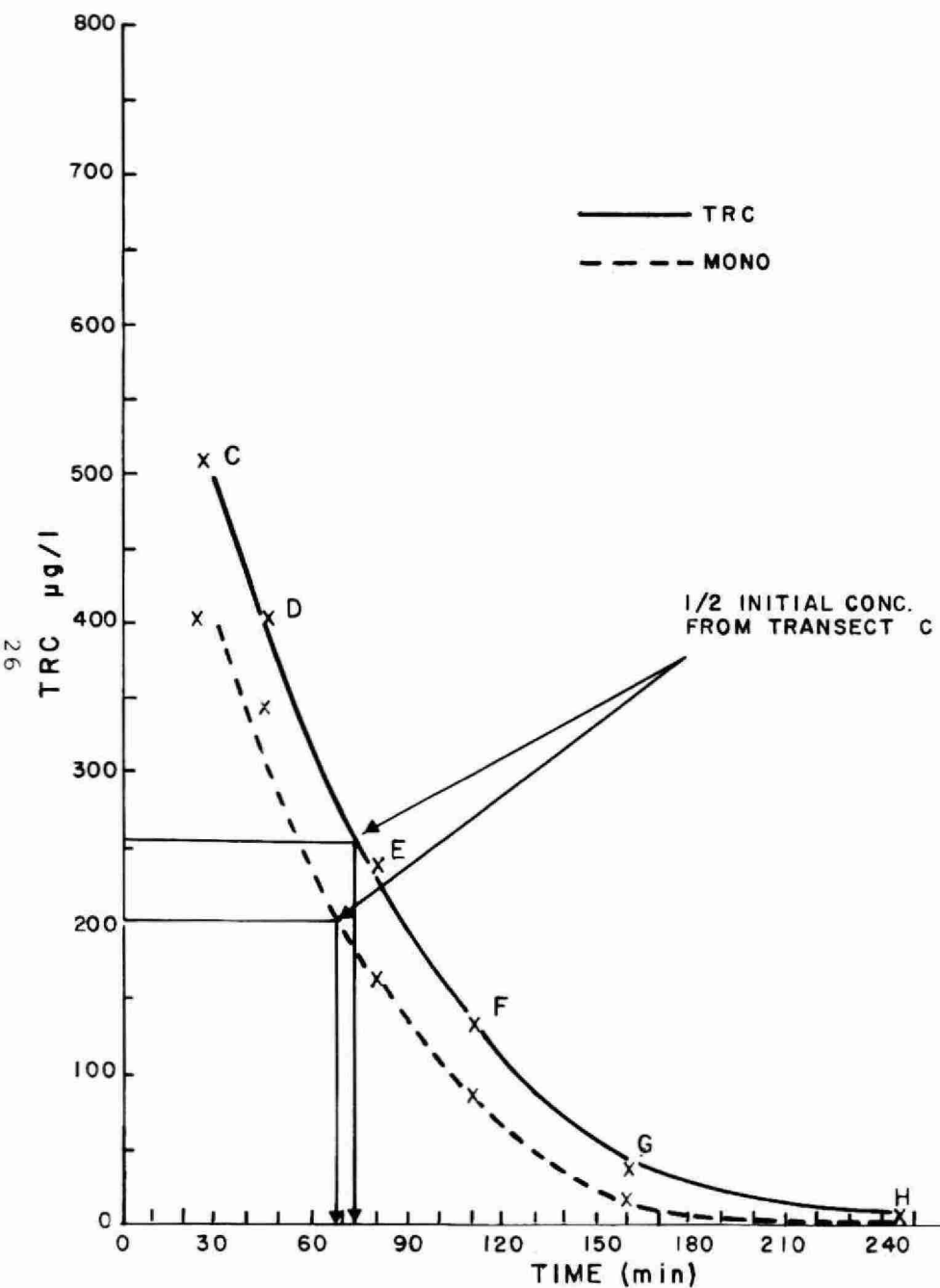


FIGURE IV (c) RUN N° 3 - AURORA CREEK AUGUST 18, 1976

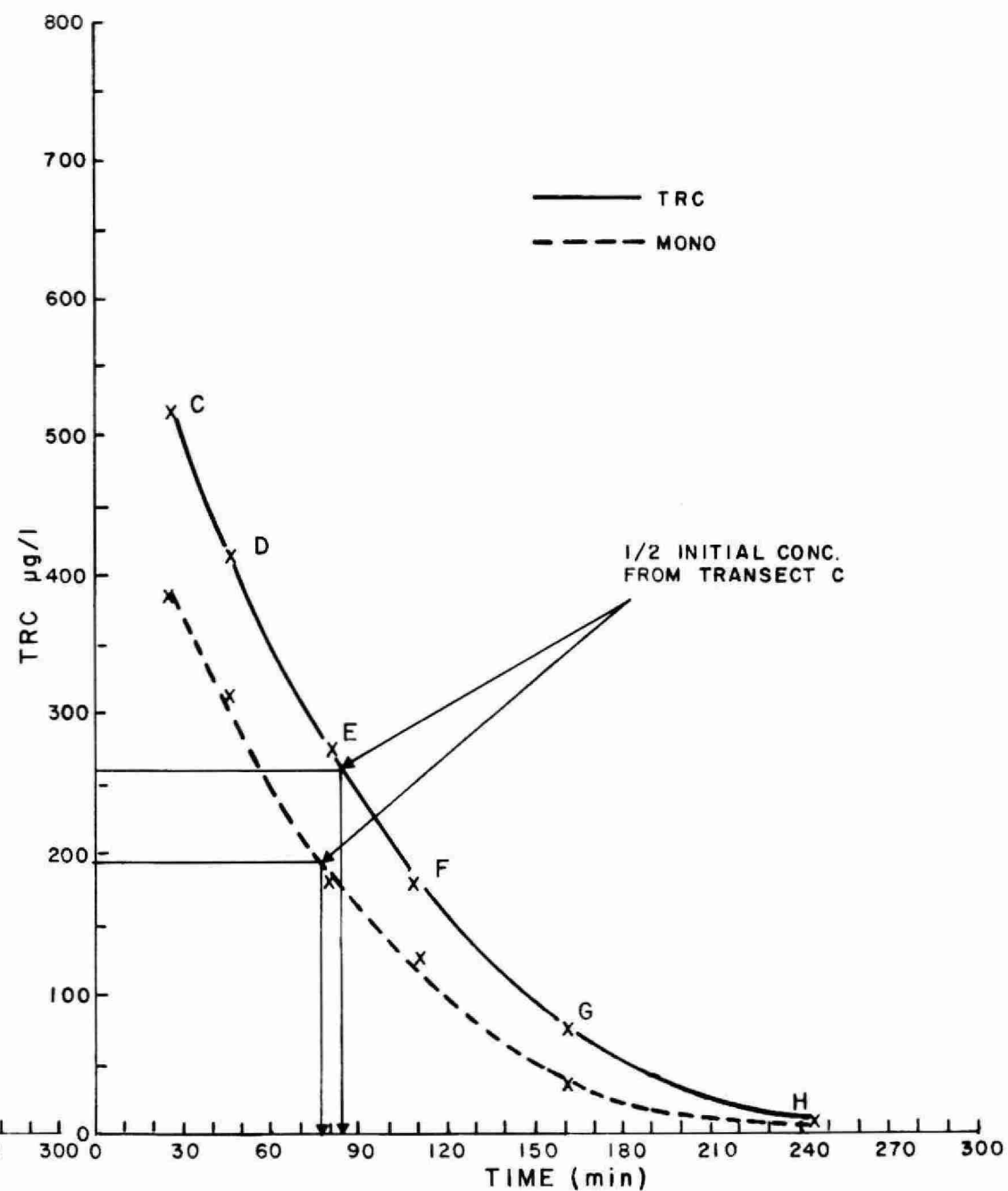


FIGURE IV (d) RUN N° 4 - AURORA CREEK AUGUST 18, 1976

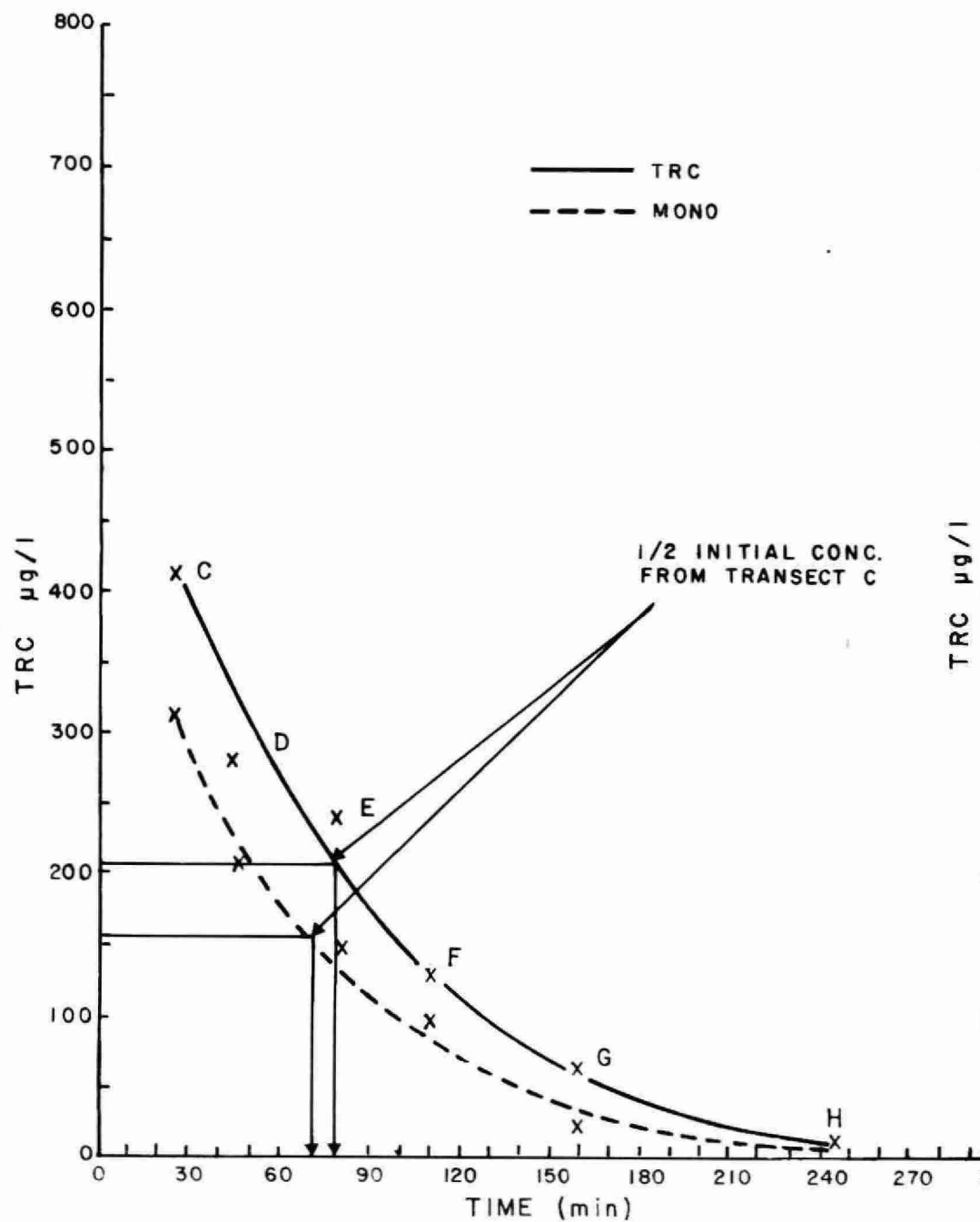


FIGURE IV (e) RUN N° 5 - AURORA CREEK AUGUST 19, 1976

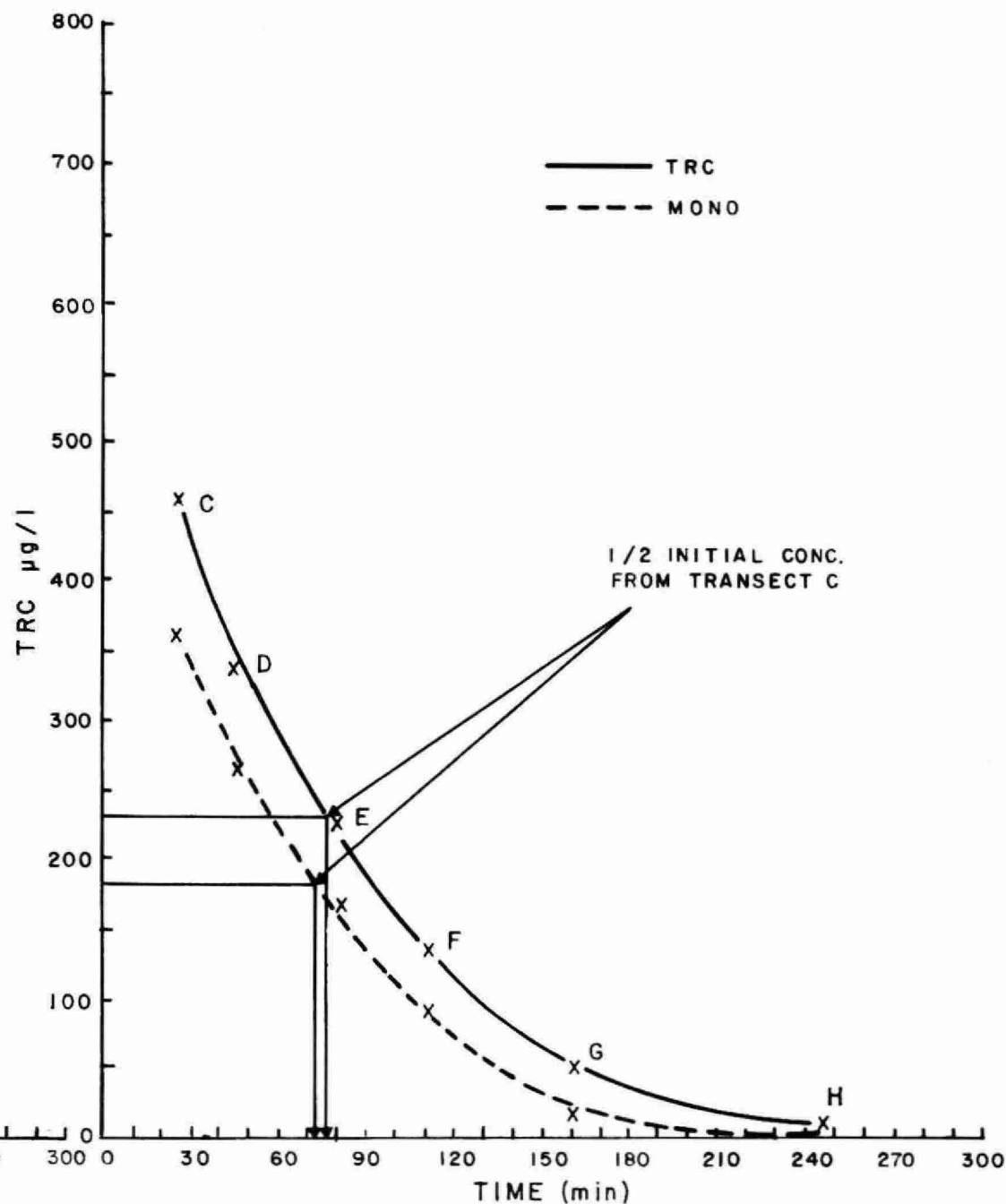


FIGURE IV (f) RUN N° 6 - AURORA CREEK AUGUST 19, 1976

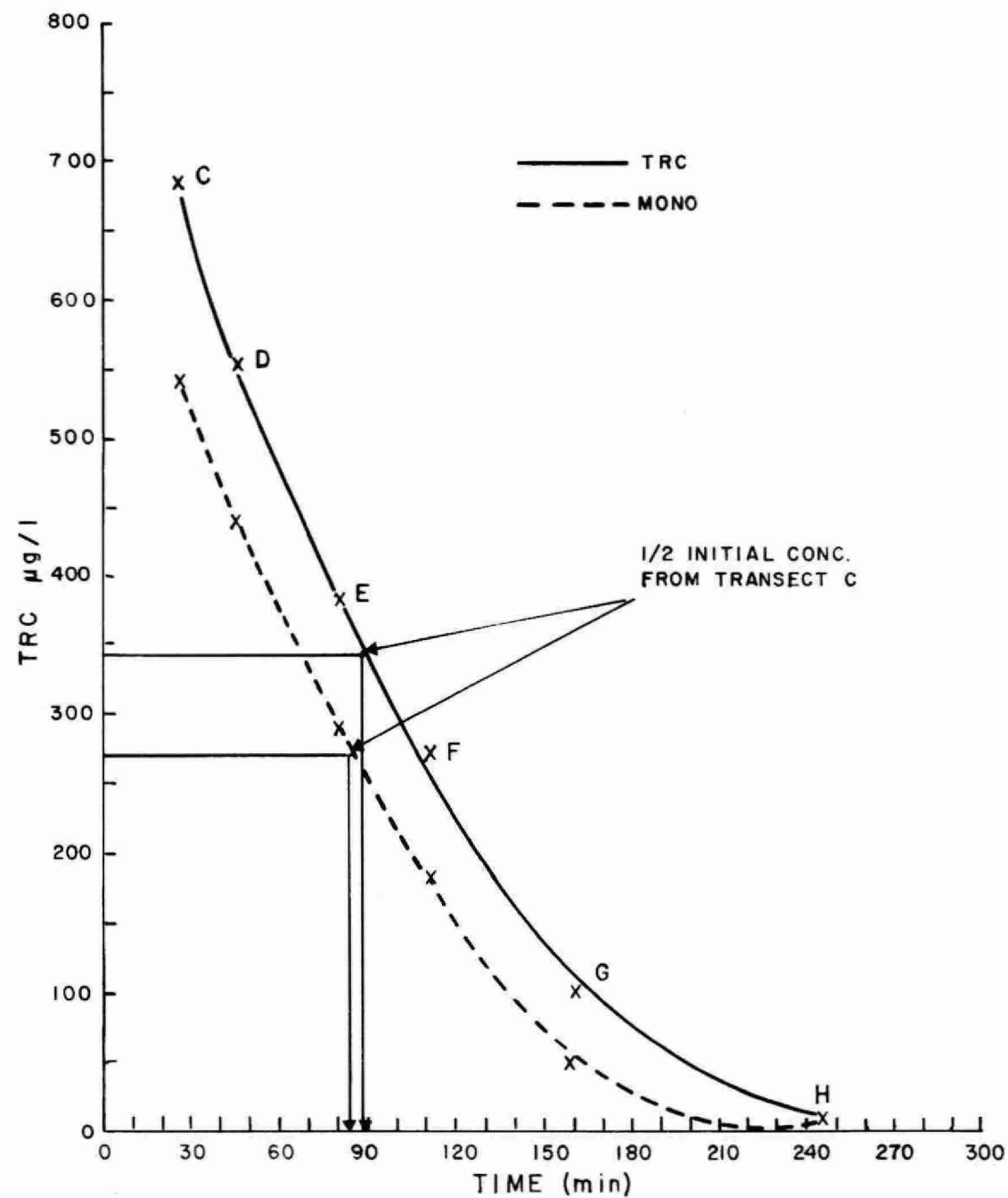


FIGURE IV (g) RUN N° 7- AURORA CREEK AUGUST 19, 1976

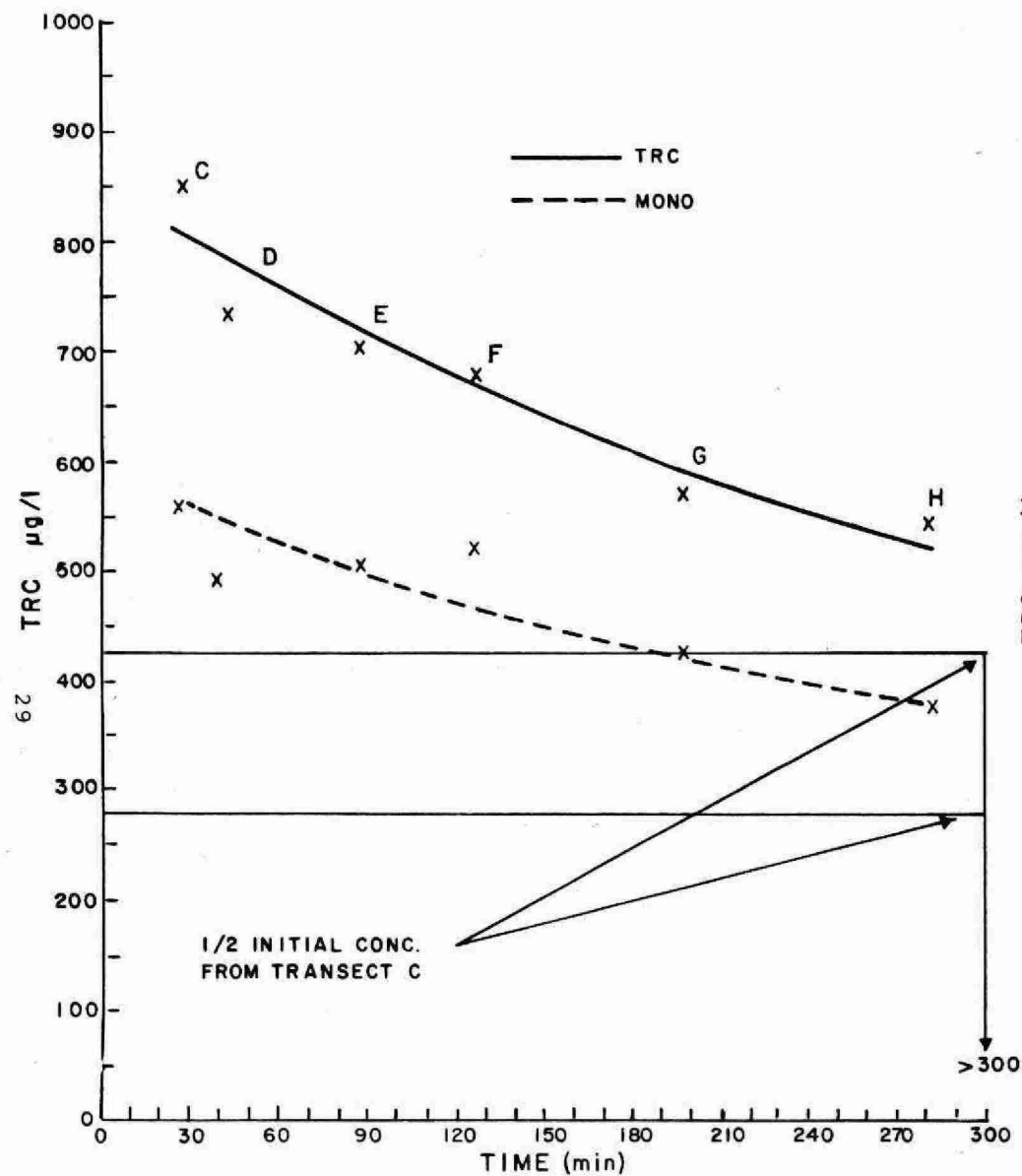


FIGURE V (a) RUN N° 1 - AURORA CREEK FEB. 9, 1977

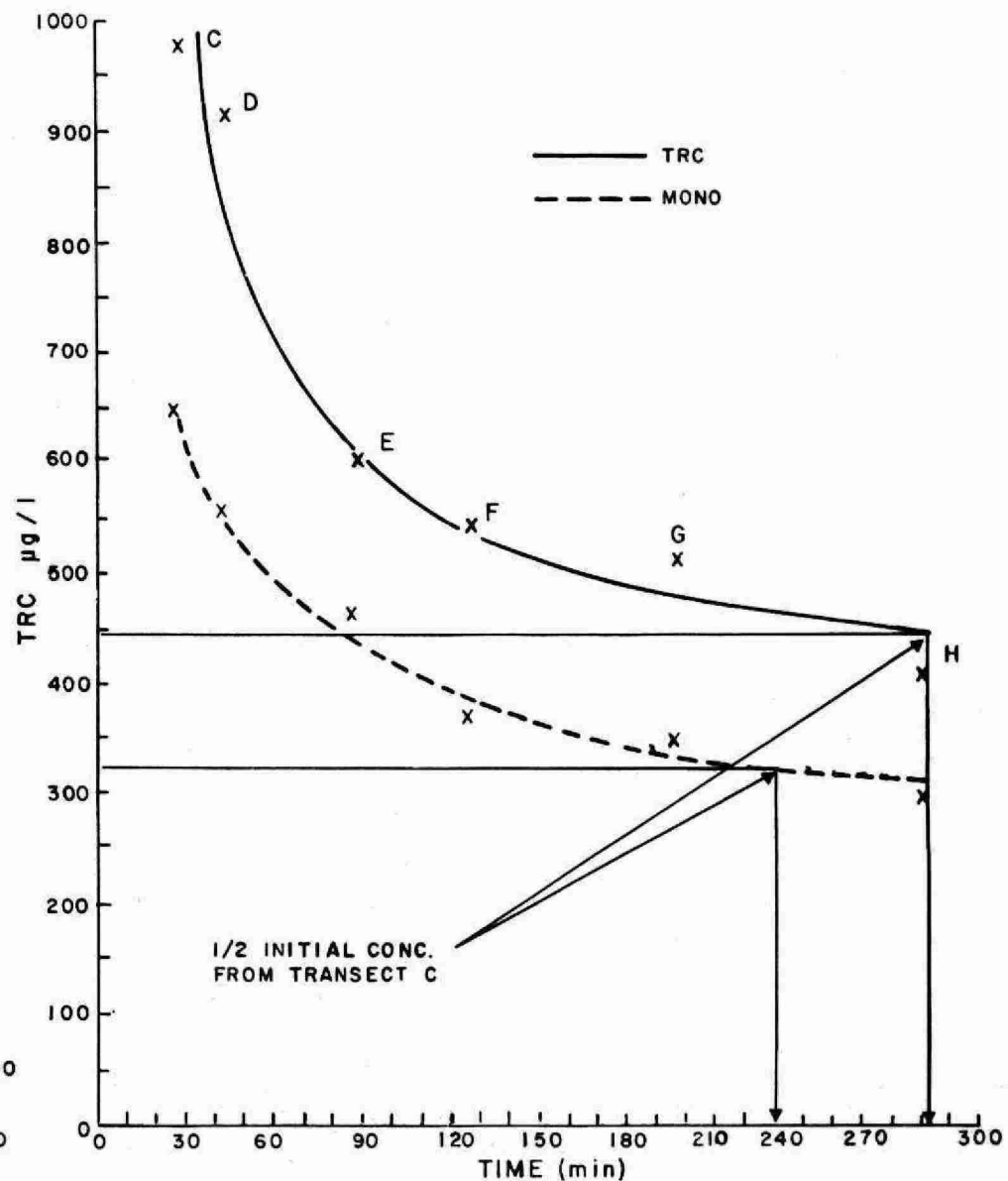


FIGURE V (b) RUN N° 2 - AURORA CREEK FEB. 9, 1977

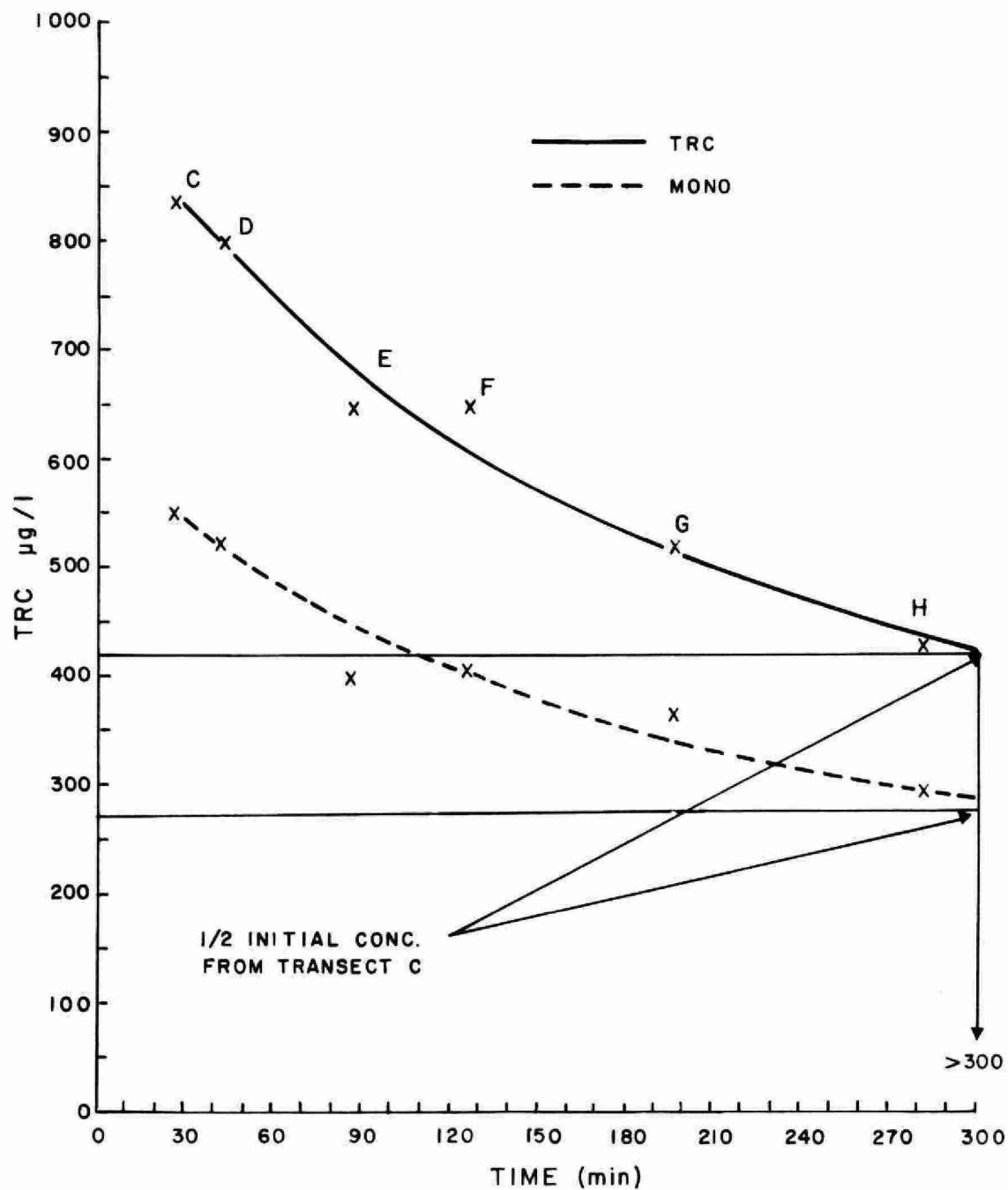


FIGURE V(c) RUN N° 3 - AURORA CREEK FEB. 9, 1977

APPENDIX B

TABLES

TABLE I

NUMBER OF SAMPLES/STATION

Survey	DO/Temp.	BOD's	N	C	Cond.	Cl ⁻	TRC	pH
Brantford (Summer)	4	4	3	4	4	4	4	4
Alliston (Summer)	5	5	3	5	5	5	5	5
Aurora (Summer)	7	5	3	5	5	5	7	7
Aurora (Winter)	4	4	4	4	4	4	4	-
Bolton (Winter)	3	3	3	3	3	3	3	-

TABLE II

SUMMARY OF TOTAL RESIDUAL CHLORINE DATA ($\mu\text{g/l}$) BRANTFORD - GRAND RIVER

Aug. 5-6, 1976

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		11:00 AM- 2:05 PM	3:30 PM- 6:12 PM	9:08 PM- 2:05 AM	4:32 AM- 9:30 AM				
Control		0	0	0	0				0
Outfall-1		1048	880	1416	2288				1408
Outfall-2		992	920	1376	2272				1390
S1		0	0	0	0				0
S2		0	0	0	0				0
S3		4	10	9	9				8
S4		14	30	34	29				27
S5	2 min.	28	45	121	132				82
A1		0	0	0	0				0
A2		0	0	0	0				0
A3		11	39	35	80				41
A4		4	41	9	13				17
A5	5 min.	1	6	6	10				6
T1		0	0	2	0				0.5
T2		0	0	5	6				3
T3		0	0	1	3				1
T4		0	5	0	3				2
T5	7.7 min.	0	10	3	4				4
B1		1	0	0	2				0.8
B2		1	0	3	3				2
B3	10 min.	0	6	3	0				2
C1, C2	17.8 min.	0	0	0	0				0

TABLE III

SUMMARY OF TOTAL RESIDUAL CHLORINE DATA ($\mu\text{g/l}$) ALLISTON - BOYNE RIVER

Aug. 11-12, 1976.

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		Preliminary	9:00 AM - 1:35 PM	4:40 PM - 7:45 PM	9:25 PM - 1:00 AM	3:20 AM - 6:40 AM	9:30 AM - 12:10 PM		
Control		0	0	0	0	0	0		0
Outfall		1272	1320	1232	768	1120	1408		1187
A _{1/2}		N.S.	N.S.	N.S.	57	184	420		220
A1		296	48	0	29	12	0		64
A2		52	0	0	0	0	0		9
A3		8	0	0	0	0	0		1
A4		0	0	0	0	0	0		0
A5	2 min.	0	0	0	0	0	0		0
B _{1/2}		N.S.	N.S.	N.S.	N.S.	N.S.	34		34
B1		45	30	8	5	30	41		27
B2		10	23	0	0	9	20		10
B3		0	4	0	0	0	5		2
B4		0	0	0	0	0	0		0
B5	5 min.	0	0	0	0	0	0		0
C1		81	15	0	4	4	7		19
C2		58	10	0	2	0	5		13
C3		20	5	0	2	0	0		5
C4	9 min.	0	3	0	0	0	0		0.5
Salada Foods	-	N.S.	0	0	0	0	0		0
D	109 min.	0	0	0	0	0	0		0
E	194 min.	0	0	0	0	0	0		0

N.S. = Not Sampled

TABLE IV

SUMMARY OF TOTAL RESIDUAL CHLORINE DATA ($\mu\text{g/l}$) AURORA - AURORA CREEK

Aug. 18-19, 1976

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		9:40 AM-11:50 AM	2:00 PM-3:45 PM	5:30 PM-8:05 PM	9:15 PM-10:55 PM	1:20 AM-3:40 AM	5:25 AM-7:15 AM	9:10 AM-10:30 AM	
Control		0	0	0	0	0	0	0	0
Outfall		1784	1216	1440	1496	1488	1704	1624	1536
A		688	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-
A1	2 min.	N.S.	928	1168	960	840	768	1360	1004
A2		N.S.	424	456	464	256	240	792	439
B	10 min.	800	508	612	704	440	452	788	615
C	25 min.	696	364	508	520	412	456	684	520
D	45 min.	540	300	404	416	280	336	552	404
E	80 min.	432	214	238	276	240	226	382	287
F	110 min.	274	138	132	180	128	136	272	180
G	160 min.	174	66	41	79	64	51	100	82
H	245 min.	23	11	6	8	12	11	7	11
J	≈ 360 min.	0	0	0	N.S.	N.S.	3	N.S.	0.8

N.S. = Not Sampled

TABLE V

SUMMARY OF MONOCHLORAMINE DATA ($\mu\text{g/l}$) AURORA - AURORA CREEK

Aug. 18-19, 1976

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		9:40 AM-11:50 AM	2:00 PM-3:45 PM	5:30 PM-8:05 AM	9:15 PM-10:55 PM	1:20 AM-3:40 AM	5:25 AM-7:15 AM	9:10 AM-10:30 AM	
Control		0	0	0	0	0	0	0	0
Outfall		1440	1024	1104	1136	1120	1340	1296	1203
A		568	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	-
A1	2 min.	N.S.	896	960	752	664	568	1120	827
A2		N.S.	308	392	376	200	184	688	358
B	10 min.	632	408	472	560	356	364	640	490
C	25 min.	560	284	404	388	312	360	540	407
D	45 min.	456	244	344	312	204	264	440	321
E	80 min.	352	120	166	180	152	168	288	204
F	110 min.	196	90	86	124	96	92	180	123
G	160 min.	124	19	21	36	22	16	50	42
H	245 min.	0	0	0	0	0	0	0	-
J	\approx 360 min.	0	0	0	N.S.	N.S.	0	N.S.	-

N.S. = Not Sampled

TABLE VI

SUMMARY OF DICHLORAMINE DATA ($\mu\text{g/l}$) AURORA - AURORA CREEK

Aug. 18-19, 1976

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		9:40 AM-11:50 AM	2:00 PM-3:45 PM	5:30 PM-8:05 PM	9:15 PM-10:55 PM	1:20 AM-3:40 AM	5:25 AM-3:40 AM	9:10 AM-10:30 AM	
Control		0	0	0	0	0	0	0	0
Outfall		0	0	0	120	120	144	0	55
A		0	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	—
A1	2 min.	N.S.	0	0	0	0	0	0	0
A2		N.S.	0	0	0	0	0	0	0
B	10 min.	0	0	0	0	0	0	0	0
C	25 min.	0	0	0	0	0	0	0	0
D	45 min.	0	0	0	0	0	0	0	0
E	80 min.	0	0	0	0	26	0	0	4
F	110 min.	8	0	0	0	26	0	0	5
G	160 min.	0	0	0	20	24	20	0	9
H	245 min.	17	8	0	0	13	12	18	10
J	\approx 360 min.	0	0	0	N.S.	N.S.	0	N.S.	—

N.S. = Not Sampled

TABLE VII

SUMMARY OF TOTAL RESIDUAL CHLORINE DATA ($\mu\text{g/l}$) AURORA - AURORA CREEK

Feb. 9, 1977

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		2:11 PM- 5:07 PM	7:13 PM- 8:05 PM	9:15 PM- 10:10 PM					
Outfall		1940	N.S.	N.S.					-
A1	1 min.	1720	1680	1790					1730
A1.5		1120	N.S.	N.S.					-
A2		680	1040	460					727
B1		860	N.S.	N.S.					-
B2		760	N.S.	N.S.					-
B	6 min.	800	890	816					835
B3		840	N.S.	N.S.					-
C1		850	N.S.	N.S.					-
C	25 min.	850	980	840					890
C2		820	N.S.	N.S.					-
D1		736	N.S.	N.S.					-
D	41 min.	N.S.	920	800					860
D2		732	N.S.	N.S.					-
E	86 min.	704	604	648					652
F	125 min.	680	544	648					624
G	196 min.	572	516	520					536
H	281 min.	544	412	428					461
J	450 min.	360	N.S.	N.S.					-

N.S. = Not Sampled

TABLE VIII

SUMMARY OF MONOCHLORAMINE DATA ($\mu\text{g/l}$) AURORA - AURORA CREEK

Feb. 9 1977

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		2:11 PM- 5:07 PM	7:13 PM- 8:05 PM	9:15 PM- 10:10 PM					
Outfall		1200	N.S.	N.S.					-
A1	1 min.	1000	1060	1190					1083
A1.5		640	N.S.	N.S.					-
A2		460	710	300					490
B1		560	N.S.	N.S.					-
B2		480	N.S.	N.S.					-
B	6 min.	600	580	512					564
B3		530	N.S.	N.S.					-
C1		570	N.S.	N.S.					-
C	25 min.	560	650	552					587
C2		620	N.S.	N.S.					-
D1		480	N.S.	N.S.					-
D	41 min.	-	560	524					542
D2		504	N.S.	N.S.					-
E	86 min.	504	464	400					456
F	125 min.	520	372	408					433
G	196 min.	424	352	366					381
H	281 min.	376	300	296					324
J	450 min.	216	N.S.	N.S.					-

N.S. - Not Sampled

TABLE IX

SUMMARY OF DICHLORAMINE DATA ($\mu\text{g/l}$) AURORA - AURORA CREEK

Feb. 9, 1977

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		2:11 PM- 5:07 PM	7:13 PM- 8:05 PM	9:15 PM- 10:10 PM					
Outfall		320	N.S.	N.S.					-
A1	1 min.	440	460	510					470
A1.5		260	N.S.	N.S.					-
A2		160	240	140					180
B1		180	N.S.	N.S.					-
B2		200	N.S.	N.S.					-
B	6 min.	150	200	216					189
B3		180	N.S.	N.S.					-
C1		180	N.S.	N.S.					-
C	25 min.	180	240	208					209
C2		140	N.S.	N.S.					-
D1		112	N.S.	N.S.					-
D	41 min.	N.S.	200	188					194
D2		108	N.S.	N.S.					-
E	86 min.	88	128	144					120
F	125 min.	84	96	120					100
G	196 min.	72	80	88					80
H	281 min.	72	84	72					76
J	450 min.	80	N.S.	N.S.					-

N.S. = Not Sampled

TABLE X (a)

AURORA - AURORA CREEK

Aug. 18/19, 1976

RUN NO.	INITIAL CONC. ($\mu\text{g/l}$) AT TRANSECT C		1/2 INITIAL CONC.		TIME TO DECREASE TO 1/2 INITIAL CONC. (mins.)	
	TRC	MONOCHLORAMINE	TRC	MONOCHLORAMINE	TRC	MONOCHLORAMINE
1	696	560	348	280	92	94
2	364	284	182	142	88	75
3	508	404	254	202	74	68
4	520	388	260	194	84	78
5	412	312	206	156	78	70
6	456	360	228	180	75	71
7	684	540	342	270	88	84

TABLE X (b)

AURORA - AURORA CREEK

Feb. 9, 1977

RUN NO.	INITIAL CONC. ($\mu\text{g/l}$) AT TRANSECT C		1/2 INITIAL CONC.		TIME TO DECREASE TO 1/2 INITIAL CONC. (mins.)	
	TRC	MONOCHLORAMINE	TRC	MONOCHLORAMINE	TRC	MONOCHLORAMINE
1	850	560	425	280	>300	>300
2	980	650	490	325	283	221
3	840	552	420	226	>300	>300

TABLE XI

DECAY OF RESIDUAL CHLORINE UNDER STATIC TEST CONDITIONS

<u>Type of Sample</u>	<u>Temp.</u>	<u>TRC ($\mu\text{g/l}$)</u>	<u>Time to Decrease to $\frac{1}{2}$ Initial Conc. (hrs.)</u>
Tap Water	5 ⁰ C	606	420
Tap Water	23 ⁰ C	606	94
Spiked River	4 ⁰ C	254 *	100
Spiked River	22 ⁰ C	244 *	10
Sewage Effluent	9.5 - 20 ⁰ C	2720	7.5

* After initial chlorine demand was satisfied.

TABLE XII

SUMMARY OF TOTAL RESIDUAL CHLORINE DATA ($\mu\text{g/l}$) BOLTON - HUMBER RIVER

Feb. 16-17, 1977

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		3:00 PM-5:10 PM	10:34 AM-11:12 AM	11:40 AM-12:40 AM	12:50 PM				
Control		N.S.	0	0	N.S.				0
Outfall		N.S.	2160	6440	7760				5453
A-4	1.5 min.	432	588	1330					783
A-8		110	0	129					120
A-11		0	0	0					0
A-16		0	N.S.	N.S.					-
B-4	2 min.	304	240	568					371
B-8		82	14	38					45
B-12		0	0	0					0
B-21		0	N.S.	N.S.					-
C-3	3 min.	304	236	468					336
C-10		40	58	100					66
C-17		0	0	0					0
C-21		0	N.S.	N.S.					-
D-6	4 min.	142	126	232					167
D-12		22	14	30					22
D-20		0	0	0					0
D-26		0	N.S.	N.S.					-
E-7	6.25 min.	46	N.S.	N.S.					-
E-15		38	64	120					74
E-23		30	N.S.	N.S.					-

N.S. = Not Sampled

TABLE XII

SUMMARY OF TOTAL RESIDUAL CHLORINE DATA ($\mu\text{g/l}$) BOLTON - HUMBER RIVER Feb. 16-17, 1977

Sample Number	Time of Travel	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Average Value
		3:00 PM-5:10 PM	10/34 AM-11:12 AM	11:40 AM-12:40 PM					
F-8	10 min.	0	N.S.	N.S.					-
F-16		0	60	114					87
F-24	19 min.	0	N.S.	N.S.					-
FF		N.S.	N.S.	106					-
G		N.S.	N.S.	104					-

N.S. = Not Sampled

[illegible]

MOE/EXT/ANRB

Wisz, S F

Extent, magnitude

and decay rates of ~~total~~ anrb

residual chloro _{c.1} in sewage _{a aa}

